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What is the competitive advantage? Exploring the intersection of charter schools and alternative teacher certification upon STEM outcomes

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What is the competitive advantage? Exploring the intersection of charter schools and alternative teacher certification upon STEM outcomes

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Abstract

What is the competitive advantage? Exploring the intersection of charter schools and alternative teacher certification upon STEM outcomes

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Alternative teacher certification pathways, public charter schools, and other market-based reforms have become staples of the current educational landscape in the United States. Since their inception, both alternative teacher preparation pathways and public charter schools have experienced tremendous growth. Extant research has investigated the effects of these reforms individually; however, little work has explored their joint impact on educational outcomes. In addition, research has not investigated how these two reforms have influenced student performance and participation in the STEM disciplines, despite the fact that influential government documents cite poor performance in STEM as a key reason why education reform is desperately needed. The goal of this dissertation project is to explore how the expansion of charter schools and alternative certification programs have independently and jointly impacted student engagement with STEM disciplines, with particular attention to the mechanisms by which these reforms have either hindered or supported student engagement.

This dissertation project consists of three distinct, yet complimentary, studies that explore various aspects of how charter schools and alternative certification pathways have

independently and jointly impacted student outcomes in STEM. The first study expands upon earlier work that explored differences in STEM course offerings and course-taking patterns between charter and non-charter schools. Specifically, this study investigates how students' enrollment in charter schools and in different kinds of STEM courses at the secondary level impact post-secondary enrollment and post-secondary degree attainment. Although charter schools increase the likelihood that students enroll in post-secondary institutions, charter school graduates are no more likely than their peers from non-charter district schools to earn post-secondary degrees in four years. The types of STEM courses in which students were enrolled at the secondary level are, however, associated with differential likelihoods of both pursuing post-secondary education and earning post-secondary degrees.

The second study identifies and explores how traditionally and alternatively certified teachers are assigned to STEM courses in charter and non-charter schools. Alternative certification and charter schools are both associated with increased likelihood of teacher mobility: either that teachers teach different STEM courses from one year to the next, find employment in different campuses, or leave the profession entirely. Compared to traditionally certified teachers, alternatively certified teachers are more likely to be reassigned to "low-stakes" STEM courses, in which results from standardized exams used to evaluate school quality are not published publicly. Finally, results indicate that the type of STEM course to which a teacher is assigned in one year impacts the type of STEM course that he or she will teach in the subsequent year, suggesting that there are some common pathways between course assignments across academic years.

The final study of this dissertation uses to different methods to estimate the joint causal effect of alternative teacher certification and charter schools upon student performance on standardized exams in STEM subjects. Results from this study indicate there is no joint causal effect of teacher preparation pathway and school sector upon student performance on standardized exams in STEM disciplines and that alternative certification negatively impacts student performance. The effect of charter schools, however, is sensitive to the model specification, underscoring the importance of articulating the assumptions made when pursuing causal inference with observational data.

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Chapter 1: Introduction

Alternative teacher certification pathways and public charter schools have become staples of the current educational landscape in the United States. The growth of alternative teacher preparation pathways and public charter schools nationwide has been spurred, in part, by a political climate seeking to disrupt the traditional education system, which has often been cast and perceived as inefficient and underperforming (National Commission on Excellence in Education, 1983). In contrast to traditional teacher preparation pathways, in which pre-service teachers obtain certification through university-based programs after enrolling in coursework and completing supervised student-teaching coordinated by the university, alternative certification programs, typically offered through private companies, provide pre-service teachers an accelerated route to certification in which they become teachers of record without completing student teaching and while continuing to enroll in coursework. Charter schools are similarly put forth as an alternative to the “traditional” public schools that are housed in districts and serve their local communities. In contrast to “traditional” public schools, charters typically operate independently of local districts and have greater autonomy over curricular, financial, and staffing decisions. As such, charter schools are intended to provide communities with educational options outside of their local districts.

Since their inception, both alternative teacher preparation pathways and public charter schools have expanded rapidly throughout the United States. After the first charter school in the United States opened in Minnesota in 1992, charter schools have expanded to 42 states and the District of Columbia (NAPCS, 2018). As of the 2017-2018 school year, the National Association of Public Charter Schools (NACPS) reported that more than 3.2 million students were enrolled in over 7000 charter schools operating nationwide (NAPCS, 2018). The number of alternative teacher preparation programs across the nation has similarly grown since the first alternative teacher preparation program was established in Virginia in 1982, with all states and the District of Columbia providing alternative routes to certification by 2007 (Suell & Piotrowski, 2007).

Political and academic commentators have long expressed concern over an incapable teacher work force and the inability of the public education system writ large to meet the United States' economic and national security needs. In an article published in *Harper's Magazine* entitled "Can Our Teachers Read and Write?" Koerner (1954) described the nature of the perceived ineptitude of the teaching force:

> There has long been a suspicion in university circles that a large number of teachers in our primary and secondary schools are totally incompetent for the job… [T]o my own astonishment, I have recently turned up a great deal of specific evidence to support the fears of the colleges. (p. 79)

Moreover, in the introduction to Koerner's 1963 book, *The Miseducation of American Teachers*, Sterling McMurrin (1963), former United States Commissioner of Education, opined, "[W]hatever his conception of the value of education, our average citizen has taken it for granted that teaching, especially in the secondary and elementary schools, is a profession entirely appropriate for persons of second- or third-rate ability" (p. x). McMurrin (1963) continued:

> Teaching is an interesting and exciting way of life and now when it is so entirely clear that nothing less than our national security and well-being depend on the quality of teaching in our schools, we should insist that no task that our society now faces deserves more serious and competent attention than that of securing the best education for prospective teachers that our resources can provide. (p. xiii)

The quality (or the perceived lack thereof) of teacher preparation programs and the teacher work force in the United States is not the only aspect of the public education system that has been on the receiving end of negative political and public attention. 1983's *A*

Nation at Risk: The Imperative for Educational Reform prepared by the National Commission on Excellence in Education expressed in no uncertain terms that the dire state of the entire public education system warranted the urgent attention of the Nation. This document detailed how the United States' "once unchallenged preeminence in commerce, industry, science, and technological innovation" was at risk due to the "rising tide of mediocrity" characteristic of the public education system (p. 112).

Rhetoric highlighting the inadequacy of teacher preparation and public education in the United States, such as that illustrated in the preceding excerpts, has been used to substantiate calls for widespread education reform in both public and political domains. Such discourse has often focused upon inequitable educational outcomes by socioeconomic demographics or poor preparation in the STEM (science, technology, engineering, and mathematics) disciplines (e.g., Guggenheim, 2010; National Commission on Excellence in Education, 1983; U.S. Department of Education, 2009). For example, *Waiting for Superman*, a 2010 documentary that received widespread attention, positioned charter schools as a preferable alternative for low-income families who are disproportionately served by underperforming public schools with ill-equipped teachers (Guggenheim, 2010). In one scene, *Waiting for Superman* describes the "dance of the lemons," a practice in which ineffective teachers with tenure in non-charter public school[1] districts are simply transferred from one school to another because these teachers cannot be fired. Charter schools, by contrast, are positioned as having greater autonomy in staffing with the freedom to both fire teachers who do not meet expectations and recruit highly effective teachers from non-traditional pathways.

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[1] Typically, research differentiates charter schools from non-charter schools by labeling the latter "traditional public schools." This term fails to acknowledge the heterogeneity of educational paradigms within public school districts, and instead suggests that schools within public districts operate under a standardized and antiquated model. Since there is substantial variability among district schools, this work uses "non-charter public schools" to distinguish between district-operated schools and charter schools.

Similarly, several government documents, including those prepared at the behests of the Reagan, H. W. Bush, Clinton, W. Bush, and Obama administrations, have cited inequitable educational outcomes and attainment by socioeconomic status to promote agendas that support improvements in teacher recruitment and training in addition to instructional innovation within public schools more generally (Recovery Act, 2009; Goals 2000, 1994; No Child Left Behind, 2002; National Commission on Excellence in Education, 1983). In addition to citing inequitable educational participation, these documents also highlight the United States' declining status as an economic, military, and technological leader to call for improved STEM preparation. In aggregate, these concerns have resulted in increased public and political support for and the sustained growth of alternative teacher preparation programs and charter schools nationally.

The goal of this dissertation project is to explore how alternative teacher preparation pathways and charter schools have jointly impacted student performance and attainment in STEM disciplines by analyzing state-wide data from Texas. Although alternative certification programs and charter schools are educational reforms that were spawned independently, they share ideologically similar foundations in that they are both instantiations of market-based reforms designed to spur innovation by expanding options and introducing competition within the public education sector. Moreover, alternative certification and charter schools have intersected in several practical ways. Under recent presidential administrations, federal funding has been used to encourage states to expand both alternative teacher certification pathways and charter schools (DeVos, 2017; U.S. Department of Education, 2009), exemplifying how political advocates offer these reforms jointly as solutions to the problems facing public education. The close relationship between alternative certification and charter schools is further exemplified by the fact that the founder of the Knowledge Is Power Program (KIPP), a charter organization with national reach, was founded by a Teach for America alumnus (Kretchmar, 2014) and that alternatively certified teachers are overrepresented in charter schools (Cannata & Penaloza, 2012).

Despite evidence that these concurrent reforms are interrelated, the effects of alternative teacher certification and charter schools upon student outcomes have largely been investigated independently. Charter school researchers have explored how charter schools affect student performance on standardized exams, with results suggesting that charter school impacts depend upon both the context in which charter schools are situated and the educational models adopted by individual charter schools (M. A. Clark et al., 2015; Dobbie & Fryer, 2011; Gleason et al., 2010). Other charter school researchers have investigated the effects of charter schools on longer term student outcomes, such as post-secondary enrollment and future earnings, with results suggesting that students who attended charter schools enroll in post-secondary institutions at higher rates but do not benefit from increased earnings in their professional careers (Davis & Heller, 2019; Dobbie & Fryer, 2016; Place et al., 2019). Research on alternative teacher certification programs has explored whether teachers from alternative programs are more or less effective than traditionally prepared teachers at improving student performance on standardized exams. Although there is research to suggest that traditionally certified teachers are more effective than alternatively certified teachers at improving student performance on standardized exams (Marder et al., 2020), results from other studies indicate that it is difficult to assess the efficacy of individual teacher preparation programs due to noisy statistical estimates (von Hippel et al., 2016).

While investigating the independent effects of alternative teacher preparation programs and charter schools upon student outcomes is certainly important given the expanding role these reforms play in the national educational landscape, it is also important to investigate the joint effects of these reforms. Since alternative teacher certification pathways and charter schools share ideologically similar foundations, investigating the independent effects of these reforms has not allowed researchers to evaluate whether or not the effects of one reform are moderated by the other. I aim to address this gap in the literature with my dissertation project by conducting studies to better understand the full breadth of how market-based reforms impact students and teachers.

When investigating how charter schools and alternative certification programs affect students and teachers, I focus specifically upon the STEM disciplines. As evidenced by excerpts referenced earlier, poor preparation in STEM disciplines in addition to inequitable educational outcomes by socioeconomic status are cited as evidence that the United States' public education system is failing (National Commission on Excellence in Education, 1983; U.S. Department of Education, 2009). Although these two issues are typically positioned as being independent of one another, scholars have argued that "poor preparation" in STEM reflects disparate educational participation along socioeconomic divisions (Salzman, 2013). Given both that educational reformers express concern over the quality of STEM education in the United States and regarding equitable educational participation and that alternative certification programs and charter schools have expanded under the backdrop of these concerns, I argue that it is imperative to research whether or not these market-based reforms are effective at addressing some of the concerns that have been cited to substantiate calls for reform within the United States public education system.

In the following two sections, I chronicle brief histories of the alternative teacher certification movement and of the charter school movement. Then, I discuss the ways in which educational reformers have cited inequitable educational achievement and poor performance in STEM to garner support for educational reform. The goal of providing these overviews is to contextualize the broader research agenda I pursue in this dissertation project and the specific research questions and studies I conduct in pursuit of this agenda. In the final sections of this introductory chapter, I introduce the specific studies included in this dissertation project and describe the data set analyzed.

“Our Failing Teachers”: Justifying Alternative Teacher Certification

Formal teacher preparation in the United States began with normal schools in the mid 19th century (Fraser, 2007). Normal schools were established with the goal of professionalizing teaching: “the founders…[saw] them as model institutions that would establish high-quality professional preparation for teachers along with a strong professional identity” (Labaree, 1996, pp. 30–31). As the number of students enrolling in elementary and secondary schools grew around the turn of the century, normal schools experienced pressure to meet an increased demand for teachers. Therefore, producing a large quantity of teachers often took precedence over ensuring the quality of candidates admitted to normal schools (Sedlak, 1989). Through the second half of the 19th century and into the early 20th century, the curricula, admissions requirements, and academic rigor between normal schools were highly varied (Fraser, 2007). On account of this variation, there were movements near the end of the 19th century to push teacher preparation toward greater standardization by centralizing teacher certification at the state level (Sedlak, 1989).

With increased standardization, admissions requirements for normal schools also changed. Prior to the 1920’s, comparatively few normal schools required a high school diploma for admission, but by the 1920’s a high school diploma became the norm for admissions to normal schools (Fraser, 2007). Accompanying this shift in admissions requirements, normal schools began to increase the rigor of their curricula, making their academic programs commensurate with other baccalaureate programs and rebranding themselves as teacher’s and state colleges. By the 1930’s, normal schools typically offered four-year programs leading to baccalaureate degrees, due, in part, to secondary schools increasingly recruiting university graduates (Fraser, 2007; Labaree, 1996; Sedlak, 1989).

As normal schools morphed into teacher's colleges, however, they became a more accessible form of higher education than other universities, and therefore attracted students who were not necessarily interested in teaching but instead desired to earn a post-secondary degree so they could ultimately gain entry into other professions. As such, many normal schools offered general liberal arts classes to students at the expense of rigorous coursework in teacher preparation (Labaree, 1996). Labaree (1996, 2004) argues that the emphasis on producing quantity over quality combined with a decline in the rigor of teacher education coursework in normal schools resulted in a negative view of teacher preparation that persisted after normal schools became teacher's colleges and ultimately colleges of education. Importantly, the transition of normal schools to teacher's colleges was emblematic of a deepening national concern both over the adequate preparation of teachers through rigorous academic coursework and over the increased demand for teachers resulting from the growth in the number of students attending elementary and secondary schools in the United States.

By the 1960's, teacher's colleges became colleges of education housed within universities amid continued pressure to increase the rigor of teacher preparation. From the 1960's to the 1990's, university-based programs dominated teacher preparation in the United States (Fraser, 2007; Labaree, 1996, 2004; Sedlak, 1989). Fraser (2007) describes how pressure to establish reputations as rigorous academic institutions and differentiate themselves from other forms of education plagued higher education:

> [L]eading universities and philanthropic agencies sought to raise standards and clarify terms for what it meant for a school to call itself a college or a university, as opposed to an academy, high school, or normal school, and to accredit those that truly fit the mold…[setting] off a never-ending struggle by virtually all higher

> education institutions to not only meet the new standards but to do so in a way that would put them at the top of a new pecking order. (p. 188)

With these broader pressures, colleges of education were forced to compete with other colleges within universities for academic prestige. Colleges of education, however, often lost out to other departments and were seen as inferior to other departments and colleges within universities (Labaree, 1996).

Negative portrayals of university-based education programs and their students have pervaded public and political commentary for decades. In *The Miseducation of American Teachers*, Koerner (1963) described several issues he believed afflicted teacher preparation in the United States. Among his concerns were: "the inferior intellectual quality of the Education faculty" (p. 17), which Koerner described as "the fundamental limitation of the field" (p. 17); "administrative inertia," which resulted in "insufficient forces to oppose the policy of stagnation" (p. 17); the poor caliber of education students; and "puerile, repetitious, dull, and ambiguous" coursework typical of education programs (p. 18). In addition to a widespread belief that the entire teacher preparation enterprise suffers from mediocrity, concern over teacher shortages have also been commonplace for decades (Sedlak, 1989). Just as these concerns were cited to reform teacher preparation throughout the first half of the 20th century, they have also been cited to promote alternative routes to teacher certification outside of traditional, university-based teacher preparation programs that came to dominate teacher preparation in the 1960's (Sedlak, 1989).

Alternative teacher certification programs[2] were first established in the early 1980's to recruit high-achieving individuals from prestigious universities to the teaching profession, targeting an untapped source of intellectually capable teachers in efforts to stave off impending teacher shortages (Sedlak, 1989). Alternative teacher certification

[2] The term "alternative teacher certification" is synonymous with "alternative teacher preparation" and "alternative teacher education," and these terms will be used interchangeably throughout this dissertation.

programs exist outside of the university-based programs, typically as accelerated pathways to teaching with fewer requirements for pre-service teachers. In contrast to university-based programs, which require pre-service teachers to complete field-based experience under the supervision of a practicing teacher before obtaining certification and starting full-time teaching position, graduates of alternative certification programs may become full-time teachers without any prior field-based experience. In addition, alternative certification programs typically have substantially less coursework than university-based certification programs, although alternatively certified teachers often continue to enroll in coursework while teaching (Darling-Hammond, 2000; Ludlow, 2013; Suell & Piotrowski, 2007).

Suell and Piotrowski (2007) note that Virginia established the first statewide alternative teacher certification program in 1982; however, pathways to teaching outside of university-based programs predate Virginia's statewide program (Fraser, 2007). The Teacher Corps was established in 1965 with the goal of recruiting graduates from prestigious schools to work in schools serving low-income and marginalized student populations (Fraser, 2007). Although pathways to teaching outside of university-based preparation programs have existed for a long time, two prominent reports following 1983's *A Nation at Risk* criticized university-based teacher preparation programs and served to galvanize support for alternative teacher certification programs. *A Nation Prepared: Teachers for the 21st Century*, prepared by the Carnegie Forum on Education and the Economy (1986), and *Tomorrow's Teachers*, prepared by the Holmes Group (1986), both described the ills of university-based education programs and advocated for reforms that would serve to increase the intellectual caliber of the teaching force and recruit more of these individuals to the teaching profession.

Although reform to teacher preparation has taken various forms since the normal schools were established in the mid 19th century, two salient themes have pervaded calls for these reforms. First, reformers have claimed that existing teacher certification programs failed to recruit capable students, were plagued with incompetence, and had mundane and intellectually dull curricula. Second, reformers have claimed that traditional teacher certification programs did not have the capacity to produce the number of teachers to meet the needs of an ever-growing student population. In the current era of market-based reforms in education, these same concerns are cited to support the expansion of alternative teacher certification programs in the United States.

"Our Failing Schools": Justifying Charter Schools and School Choice

Charter schools are publicly funded schools that are free from many of the regulations to which non-charter public school are accountable. Often, but not always, charter schools are independent from their local school districts and have greater autonomy over staffing, finance, and curriculum than non-charter public schools. Charter school proponents position them as schools of choice that empower families to withdraw from underperforming non-charter schools and instead enroll their children in schools that are best tailored to their children's needs (Anderson, 2018; DeVos, 2017). While widespread bipartisan support for market-based reforms in education was accelerated in large part by 1983's *A Nation at Risk* (C. S. Clark, 2002; Mungal, 2016; Stern, 2013; Worsnop, 1991), which proclaimed that the United States' public education system was in dire need of an overhaul given its inability to adequately educate the nation's youth (National Commission on Excellence in Education, 1983), the concept of introducing choice and competition to public education in order to increase the quality of public education originates in economist

Milton Friedman's *Capitalism and Freedom* (2002).[3] In a chapter dedicated to the role of government in education, Friedman (2002) wrote:

> If…public expenditures on schooling were made available to parents regardless of where they send their children, a wide variety of schools would spring up to meet this demand. Parents could express their views about schools directly by withdrawing their children from one school and sending them to another, to a much greater extent than is now possible. (p. 91)

In addition to more effectively meeting individual families' educational demands and "stimulating" the "development and improvement of all schools" (p. 93), Friedman (2002) argued that introducing market-like competition through parental choice within the public education system at the elementary and secondary levels would equalize educational access by giving families—particularly economically disadvantaged families—the option to send their children to higher quality schools that are more often located in neighborhoods with higher income. Rather than leading to increased segregation between schools, as some critics argued, Friedman (2002) posited that giving parents choice in public education through vouchers would instead serve to decrease the barriers that keep low-families from accessing high quality schools. Instead of being relegated to attending schools in their local districts, which receive discrepant funding due to the fact that public schools are funded through property taxes, families, through vouchers, could exercise choice and send their students elsewhere. According to Friedman, without vouchers only families of means have access to school choice because they can afford to either move into a better district or pay tuition for private schooling.

While the idea of school choice was introduced in Friedman's *Capitalism and Freedom*, the concept of charter schools was conceived by Budde in his 1988 report, *Education by Charter: Restructuring School Districts*. In this report, Budde (1988)

[3] Milton Friedman's *Capitalism and Freedom* was originally published in 1962, but the version I reference herein is a 40th anniversary edition.

envisioned an education system in which schools would be issued charters from an overseeing organization, thereby giving schools and the teachers within them greater autonomy with which to experiment in implementing creative and innovative educational models. Just as charters issued during the Age of Exploration "usually called for exploration into unknown territory and involved a degree of risk to the persons undertaking the exploration," Budde (1988) argued that charters in education would enable individuals with novel ideas for education to put those ideas into practice (p. 49). In addition, Budde (1988) proposed that schools operating under a charter would be held accountable to the charter grantor and have permission to operate for a finite time period—between 3 and 5 years. Should a charter school fail to meet its accountability benchmarks, it would not be allowed to continue its operation.

At its inception, school choice was to be realized through voucher programs, in which parents would receive vouchers to send their children to schools approved by the government, and schools could then redeem each voucher for funding commensurate with the cost of educating a single student (Friedman, 2002). Early choice programs, however, often took the form of tuition tax benefits for schooling, in which families sending their students to parochial or private schools could reduce their taxes by a certain percentage of their educational expenses, including tuition, travel to and from school, and school supplies (Worsnop, 1991). Early adopters of school choice programs included: St. Paul and Minneapolis, Minnesota; Scarsdale, New York; Philadelphia, Pennsylvania; San Jose, California; and Arlington, Virginia (C. S. Clark, 2002; Worsnop, 1991).

A major point of contention in the early days of the school choice movement was whether or not it was constitutional for the public government to provide families with vouchers that would ultimately go to parochial schools, thereby muddying a clear separation between church and state. In the 1971 court case Lemon v. Kurtzman, three criteria were established to determine whether or not government financial aid to religious schools was constitutional (Worsnop, 1991). This case established that any aid given to a parochial school must be driven by secular goals, must neither advance nor inhibit any religious ideology, and must not lead to mixing between governmental and religious organizations (Worsnop, 1991).

In his 1980 presidential campaign, Ronald Reagan ran on a platform promoting tuition tax credits to broaden school choice. As president, Reagan submitted a legislative proposal to Congress in 1982 in addition to subsequent proposals for tuition tax credits throughout his presidency, but these proposals were never enacted into law, facing tremendous opposition from the public education lobby (Worsnop, 1991). At the state level, however, school choice movements made headway. C. S. Clark (2002) reports that in the late 1980's, after *A Nation at Risk* was released, California considered legislation that would require schools to create alternate educational programs if a sufficient percentage of the parents in that school requested them, and Minnesota passed two laws allowing students to transfer between districts.

During his presidency, George H. W. Bush also promoted school choice as a key component of school reform. In 1991, President Bush released *America 2000: An Educational Strategy* to serve as guidelines for achieving educational goals developed at the 1989 National Education Summit, a meeting between President Bush and the governors of all 50 states, in Charlottesville, VA (America 2000, 1991; Bush, 1991). President Bush proposed legislation, the *America 2000: Excellence in Education Act*, which promoted school choice and other market-based reforms as necessary means to achieve the previously established National Education Goals (Bush, 1991). As articulated in *America 2000: An Educational Strategy*, school choice was proposed as a way to improve the broader public education system by promoting competition between schools, thereby inducing educational experimentation and innovation (America 2000, 1991). Moreover, this legislation also proposed accountability measures for all schools in order to empower families to make informed decisions about the efficacy of different public schools. In addition to expanding school choice, *America 2000* also called for the creation and expansion of alternative teacher certification programs in order to recruit professionals and other qualified individuals into the teaching profession who might otherwise not consider a teaching profession due to the number of barriers to entry (America 2000, 1991; Bush, 1991; Worsnop, 1991).

Although the *America 2000: Excellence in Education Act* was not written into law, elements of school choice began to expand at the state level, with charter school legislation written into law in Minnesota in 1991 and California following suit in 1992 (C. S. Clark, 2002). By the conclusion of the 1990's, charter school legislation was enacted into law in 36 states and Washington, D.C. Such growth was supported by legislation enacted in 1994 during Bill Clinton's presidency. The *Goals 2000: Educate America Act* explicitly supported school choice by providing funding for the development and expansion of charter schools (Goals 2000, 1994; Heise, 1994; Stallings, 2002). Like *America 2000: An Educational Strategy*, *Goals 2000* sought broad educational reform through school choice to address the educational "mediocrity" in the United States articulated in *A Nation at Risk* and to achieve the National Education Goals developed at the National Education Summit in 1989.

At the federal level, policies and legislation supported both by President George W. Bush and President Barack Obama continued to expand school choice by providing funding to charter schools. In 2001, George W. Bush proposed the *No Child Left Behind Act*, which established high-stakes accountability metrics for schools and required districts to allow students to transfer out of low-performing public schools and into other public charter or non-charter schools (Stallings, 2002). The *Race to the Top* program, which was a part of Barack Obama's *American Recovery and Reinvestment Act of 2009*, similarly promoted charter schools as a viable way to achieve reform and induce innovation by providing financial incentives for educational institutions to partner with nonprofit organizations with a proven record of closing the racial achievement gap (Recovery Act, 2009; Stern, 2013). In addition, the *Race to the Top* program fortified high-stakes accountability measures established in the *No Child Left Behind Act* (Stern, 2013).

That charter schools could either improve or serve as an alternate to the often underperforming public schools in urban areas led many Black and low-income, ethnic minority families to embrace the charter school movement (Shokraii, 1996). However, whereas conservative political rhetoric around charter schools emphasized the potential of competition and market-based principles to improve public education, Black charter-school advocates borrowed language from the civil rights movement and sought greater school choice due to "public schools' dismal educational record and indifference to parents" (Shokraii, 1996, p. 20). Several grass-roots movements in Black communities around the country emerged in support of school choice and charter schools: Cleveland, Ohio; Milwaukee, Wisconsin; Florida; California; Texas; and Michigan (Shokraii, 1996). While Shokraii (1996) described the policy impacts of these grass-root movements, a more recent study designed to identify what characteristics were predictive of charter schools found that states and districts with higher percentages of Black and Latinx populations were more likely to have charter schools (Stoddard & Corcoran, 2007). In addition, these authors found that states and districts with charter schools also had a greater percentage of adults with post-secondary degrees and were characterized by greater income inequality. Although support for charter schools and school choice was (and is) by no means universal, Martin and Burke (1990) cite data from a Gallup Poll indicating that twice as many participants polled supported school choice as those who did not.

EDUCATION REFORM FOR THE STEM DISCIPLINES

The alleged decline in the general quality of the United States public education system and the inferior intellect of the teachers employed within it have often been cited in public and political discourse as threatening the United States' global economic, military, and technological superiority (Carnegie Forum on Education and the Economy, 1986; Holmes Group, 1986; National Commission on Excellence in Education, 1983). Of particular concern, specifically with respect to national security and economic competitiveness, has been the quality of STEM instruction. Rudolph (2002) explains that widespread fear within the United States about superior STEM education in Russia during the Sputnik era prompted the scientific community in the United States to take a greater role in designing science curricula and instruction for the elementary and secondary levels.

Moreover, concern about inadequate preparation in STEM has been cited in several government documents to motivate calls for education reform. For example, *A Nation at Risk* described the decline in United States' performance on national science assessments and the increase in the number of students enrolling in remedial mathematics courses (National Commission on Excellence in Education, 1983). Improving United States students' achievement in math and science—more specifically, ensuring United States students' global preeminence in these disciplines—was described in both *America 2000* and *Goals 2000* (America 2000, 1991; Goals 2000, 1994). In addition to providing funding to states supportive of charter schools, N*o Child Left Behind* provided funding for the expansion of alternative teacher certification programs so that these programs could recruit highly qualified teachers with post-secondary degrees in the STEM disciplines (No Child

Left Behind, 2002). *Race to the Top*, initiated under the *American Recovery and Reinvestment Act*, prioritized STEM preparation and called for states to create environments favorable towards educational innovation, such as expanding opportunities for charter schools (Recovery Act, 2009). Although alternative pathways to teacher certification and charter schools are not necessarily positioned as reforms expressly targeted at addressing STEM education, they are at the forefront of efforts to catalyze change in an education system that is often portrayed as problematic due to concerns over the quality of STEM education.

That the United States is falling behind in STEM disciplines is a truism accepted in public and political circles: "[M]ost policymakers and industry leaders are united in their belief that the United States faces a high-tech talent crisis. The belief has become a central theme in discussions…on education and the causes of economic stagnation domestically, and on the nation's competitive position globally" (Salzman, 2013, p. 58). Seemingly, United States student performance on national standardized exams, such as the National Assessment of Educational Progress (NAEP), and on international standardized exams, such as the Programme for International Student Assessment (PISA), support these narratives. However, rather than a decline in educational performance in STEM and a lack of qualified STEM workforce in the United States, skeptics argue that concerns over these issues are misplaced and rather the real issue with STEM in the United States is inequitable participation in these disciplines (Salzman, 2013; Teitelbaum, 2003, 2014).

EDUCATION REFORM FOR EQUITY

In addition to highlighting the United States' declining status as an economic, scientific, and technological leader, government documents calling for education reform have also highlighted inequitable participation in education by ethnic and socioeconomic status. *A Nation at Risk* expressly acknowledged that although citizens were, on average, more highly educated than before, the achievement of the average high school and college graduate was lower than before. Following these observations, the authors wrote, "The twin goals of equity and high-quality schooling have profound and practical meaning for our economy and society, and we cannot permit one to yield to the other either in principle or in practice" (National Commission on Excellence in Education, 1983, p. 117). *America 2000* and *Goals 2000* also sought to eliminate the gap in achievement between socioeconomically disadvantaged ethnic minority populations and non-minority populations (America 2000, 1991; Goals 2000, 1994). The first section of *No Child Left Behind* included a number of provisions to support underachieving schools serving disadvantaged populations (No Child Left Behind, 2002). Finally, *Race to the Top* called for increased efforts for recruiting underrepresented ethnic minority populations and women to the STEM fields (U.S. Department of Education, 2009).

Discrepant participation in STEM fields is evident as early as high school. On average, Asian and White students take more credits in the physical sciences (physics and chemistry) during high school than Black, Latinx, and Native American students, although differences in biology and math credits are not as substantial (National Center for Education Statistics, 2018). Differences in STEM participation at the post-secondary level also exist along ethnic and socioeconomic lines. Of the post-secondary student population, Black, Latinx, Pacific Islander, and American Indian/Alaska Native students are underrepresented in STEM disciplines—particularly in engineering, mathematics, and the physical sciences—while White and Asian students are overrepresented in these disciplines (National Center for Education Statistics, 2018).

Rothwell (2013) reports that, as of 2011, half of all careers requiring STEM knowledge did not require workers to have a bachelor's degree in a STEM discipline. In addition, these jobs pay average salaries that are 10% higher than careers in other fields with equivalent educational requirements. Inequitable access to and participation in STEM can inhibit students' ability to pursue jobs and careers that are more lucrative. Moreover, differences in compensation between STEM and non-STEM fields are not limited to those that require less than a bachelor's degree, as Rothwell (2013) reports. Post-secondary STEM degrees are also associated with higher average earnings than non-STEM fields (Carnevale et al., 2015; National Center for Education Statistics, 2018).

In addition to the economic benefits associated with STEM careers and degrees (Carnevale et al., 2015; Rothwell, 2013), understanding of STEM content and facility with the "habits of mind" characteristic of STEM disciplines (e.g., inquiry, analytical skills, and critical thinking) are socially and professionally privileged (Metcalf, 2010). Given the benefits of STEM—both with and without post-secondary education in STEM fields—it is important for all students to have access to high quality STEM education not only for the benefit of the broader society, but also for students' own personal benefit and well-being. That socioeconomically disadvantaged and ethnic minority populations are underrepresented in STEM fields both in secondary and in post-secondary education is therefore a manifestation of inequity in STEM education.

Charter schools and alternative teacher preparation pathways are positioned by proponents as educational reforms that can promote social mobility. Moreover, adequate preparation in the STEM fields, at the secondary and post-secondary levels, is a viable way to achieve social mobility, seeing as STEM knowledge is privileged and STEM careers are associated with higher than average wages. Public education as a means for social mobility is one of three competing ideologies that Labaree (1997) argues have been at the center of educational reform movements. The three competing goals at the center of the political debate surrounding public education identified by Labaree (1997) are: public education for democratic equality; public education for social efficiency; and public education for social mobility (p. 42).

Advocates of public education for democratic equality justify this stance because "a democratic society cannot persist unless it prepares all of its young with equal care to take on the full responsibilities of citizenship in a competent manner" (Labaree, 1997, p. 42). The democratic equality goal positions education as entirely public—it is a public good meant to directly benefit and serve public interests by preparing students for "competent" democratic engagement. Those who believe public education exists for social efficiency maintain this position because "our economic well-being depends on our ability to prepare the young to carry out useful economic roles with competence" (p. 42). Whereas democratic equality is purely public, social efficiency positions education as a public good serving the needs of the private sector. In so doing, however, there is public benefit because preparing students for work in the private sector ultimately promotes the nation's economic productivity and prosperity. Finally, those who argue public education should promote social mobility believe "education is a commodity, the only purpose of which is to provide individual students with a competitive advantage in the struggle for desirable social positions" (p. 42). Advocates of education as social mobility position education as a public good serving individual students' personal interests and students as consumers of this commodity.

In describing how these three competing interests have impacted public education, Labaree (1997) argues:

> [T]he biggest problem facing American schools is not the conflict, contradiction, and compromise that arise from trying to keep a balance among educational goals. Instead, the main threat comes from the growing dominance of the social mobility goal over the others. Although this goal (in coalition with the democratic equality goal) has been a major factor in motivating a progressive politics of education over the years, the increasing hegemony of the mobility goal and its narrow consumer-

> based approach to education have led to the reconceptualization of education as a purely private good. (p. 73)

In characterizing the politics of education, ideologies that emphasize the mobility of the individual have come to dominate at the expense of public interests, namely democratic equality and social efficiency. Moreover, the goal of social mobility commodifies education in a way that is concomitant with market ideologies.

Consistent with this notion, Apple (2007) describes the scope of 2002's *No Child Left Behind* (NCLB): "The major components of the legislation center on testing and accountability but also provide inroads toward a larger agenda of privatization and marketization" (p. 109-110). Apple (2007) cautions that the education reforms promoted by this legislation served to couple high accountability, or the auditing of public schools, via standardized examinations with the marketization and privatization of public education. Apple (2007) describes that these ideologies "[have] not demonstrated much improvement in education and [have] marked a dangerous shift in our very idea of democracy…from 'thick' collective forms to 'thin' consumer-driven and overly individualistic forms" (p. 112). Moreover, these reforms "[misconstrue] and then basically [ignore] the intense debates over whose knowledge should be taught in schools…and [establish] a false consensus on what is supposedly common in the United States" (p. 112).

According to these notions, the convergence of accountability measures with marketization and privatization has served to protect dominant groups' interests and resulted in a lack of appreciation for the complexities of classroom practice and the diversity of cultural ways of knowing. Therefore, conceptions of knowing and learning as cultural practice, as described by Gutiérrez and Rogoff (2003) and Nasir and Hand (2006), are neglected in favor of promoting standardization, efficiency, and perpetuation of knowledge concordant with normative stances.

Although charter schools and alternative teacher preparation programs are lauded as reforms to improve education, some observers note that the innovations induced by market-based reforms are organizational in nature, while instruction and curricula are left unchanged (Lubienski, 2003). Moreover, scholars worry that charter school successes, such as those reported by Clark, Gleason, Tuttle, and Silverberg (2015) and Dobbie and Fryer (2016), are due, in part, to strict character education in some charter schools that is enigmatic of a "new paternalism" in which middle-class values are taught to low-income students as a means to promote social mobility (Curto & Fryer, 2014; McDermott & Nygreen, 2013). Notably, educational programs imbued with middle class values and that revert to standardized and more traditional modes of instruction are antithetical to multicultural education, in which "institutional changes must be made, including changes in the curriculum; the teaching materials; teaching and learning styles; the attitudes, perceptions, and behaviors of teachers and administrators; and the goals norms and culture of the school" (Banks, 1993, p. 4).

In addition to concerns about how "new paternalistic" approaches to education within charter schools devalue marginalized students' multicultural ways of knowing, evidence suggests that the student achievement often attributed to charter schools may instead be an artifact of "cream-skimming," in which charter schools specifically target high-achieving students from historically marginalized populations (Jabbar, 2015; Lacireno-Paquet et al., 2002). Of concern, cream-skimming serves to exacerbate inequity by limiting "choice" to families of relative privilege within low-income neighborhoods and by taking resources from other non-charter public schools who are left to serve students with lower academic achievement.

Geospatial analyses characterizing how charter schools strategically position themselves within the educational market provide additional evidence to support the notion that charter schools may engage in cream-skimming. These studies suggest that charter schools tend to be established in areas of relative privilege (e.g., higher educational attainment or greater per-capita funding) surrounding communities with socioeconomically disadvantaged populations (Glomm et al., 2005; Gulosino & dEntremont, 2011; Koller & Welsch, 2017; Saultz & Yaluma, 2017). In contrast to rhetoric that positions charter schools as means by which to provide choice to families that otherwise would not have access to educational options, evidence suggests that charter schools may be strategically recruiting students with higher academic potential in such a way that serves to boost their academic reputations and outcomes. It is therefore important for research on charter schools and other market-based reforms to attend to issues of equity when evaluating the impacts of these reforms.

AREAS FOR RESEARCH

Expanding alternative certification routes to teacher certification and increasing the number of charter schools as a means to spur innovation in public education have both been elements of education reform promoted by federal initiatives since the publication of *A Nation at Risk*. Some researchers have suggested that alternative certification and charter schools have formed an education structure that is parallel to the traditional structure in which teachers prepared in standard, university-based preparation programs work in non-charter public schools. In the theorized "parallel" education system, teachers trained in alternative certification programs are more likely to teach in charter schools (Mungal, 2016). The relationship between charter school expansion and the growth in the number of alternative teacher certification programs is also highlighted in *Waiting for Superman*: charter schools have greater autonomy over staffing and are therefore able to hire highly qualified individuals who did not come to teaching through traditional certification pathways (Guggenheim, 2010). Thus, while elements of the charter school movement and elements of teacher education reform have distinct histories, their expansions in the wave of education reform that has occurred since the publication of *A Nation at Risk* in 1983 are dependent. Despite their dependence, the bulk of the existing literature on charter schools and alternative certification programs explore the effects of these reforms independently, but do not explore the joint nature of the effects of these reforms on student outcomes.

In addition to promoting charter schools, alternative teacher certification pathways, and other market-based reforms, federal initiatives advocating these reforms have shared other common threads. Fear of the "rising tide of mediocrity" of the United States' public education system articulated in *A Nation at Risk* galvanized the public interest in educational reform in the Reagan era and sustained this interest through Obama's presidency (Heise, 1994; National Commission on Excellence in Education, 1983; Smith, 1996; Stern, 2013). Specifically, federal documents highlighted United States students' declining performance in STEM disciplines and discrepant educational achievement by socioeconomic status and ethnic identity. School choice reforms have been offered as ways to improve upon instruction by allowing schools to experiment and innovate with novel educational models, thereby leading to gains in student achievement. Alternative certification is positioned as a reform that will serve to recruit highly qualified individuals to work with disadvantaged populations, with a particular focus on recruiting teachers in the highly needed STEM disciplines.

While performance in STEM and inequitable educational participation in general have been factors that have been used to promote educational reform initiatives, most research on the effects of charter schools and alternative teacher certification routes focuses upon student outcomes on mathematics and reading exam scores, as these subjects are the most often tested at the elementary and secondary levels. Although mathematics is one of the STEM disciplines, research solely investigating student outcomes in mathematics does not provide insight into how education policy initiatives have influenced student engagement in the STEM disciplines more generally. To date, little research has been conducted to evaluate the effects of market-based reforms upon student outcomes in the STEM disciplines (beyond mathematics) or to evaluate the effects of market-based reforms upon historically disadvantaged populations' engagement with and participation in STEM, despite the fact that these concerns are highlighted in political and public discourse to advance market-based reforms. Moreover, the effects of charter schools and alternative certification programs have largely been explored independently, despite the fact that they are interconnected in many critical ways. This dissertation project seeks to address these gaps in the existing literature by exploring the ways in which the expansion of market-based reforms, specifically alternative certification pathways and charter schools, in the United States since the 1980's have jointly impacted student participation and performance in STEM disciplines with a particular focus on underrepresented ethnic minority and socioeconomically disadvantaged populations.

In pursuit of this broader research agenda, this dissertation consists of three distinct studies, each of which comprises one of the next three chapters. The research questions addressed by each study are given below:

1. How do students' STEM course-taking patterns in charter and non-charter secondary schools predict their participation in and persistence through STEM fields at the post-secondary level?
2. What factors influence the ways in which alternatively and traditionally certified teachers are assigned to teach STEM courses in charter and non-charter secondary schools? What are the characteristics of the teachers assigned to teach various STEM courses at the secondary level?

3. What is the joint causal effect of teacher certification (alternative or traditional) and school sector (charter or non-charter) upon student performance on standardized exams in STEM disciplines?

The first research question is an extension upon prior work seeking to identify differences in STEM course offerings and STEM course-taking patterns between Texas charter and non-charter secondary schools (David, 2018; David et al., 2020). Findings indicate that although charter schools are associated with increased rates of college enrollment, particularly at 4-year institutions, these benefits do not extend to post-secondary outcomes. Charter school graduates are not more likely than graduates of non-charter schools to earn post-secondary degrees.

The second research question expands upon a research project exploring the effects of certification upon student learning in STEM disciplines and a related study exploring the probability of a teacher being assigned to teach a tested STEM subject based upon that teacher's demonstrated ability to improve student test scores in prior years (David & Marder, 2018; Marder et al., 2020). Findings show that charter school employment and alternative certification are both associated with decreased likelihood of teaching the same STEM course at the same campus in a subsequent academic year. In terms of subsequent year course assignment, a teacher's prior course assignment is a strong predictor of the kind of STEM course to which he or she will be assigned in the following year.

The final research question builds upon prior work that employed a mixed crossover and randomized block research design to estimate the causal effect of certification pathway and school type upon student test score gains in STEM disciplines. In this study, I employ two causal methods to estimate the independent and joint causal effects of teacher preparation pathway and school sector upon student performance on STEM standardized exams. While results suggest that there is no causal effect due to the interaction between charter school employment and alternative teacher certification upon student performance on standardized exams, the independent effects of charter schools upon student performance on standardized exams are sensitive to model specification. Therefore, it is important for researchers to attend to the assumptions underlying the causal frameworks employed when estimating the causal effects of education reforms.

DATA AND SETTING

To address these questions, I analyze data available through the Texas Education Research Center (ERC), which collects and maintains student, school, and district level demographic and organizational data from the Texas Education Agency (TEA); student level accountability, course-taking, and course-completion data from the TEA; teacher certification data from the State Board of Educator Certification (SBEC); and individual level course-taking and course-completion data for institutes of higher education in Texas from the Texas Higher Education Coordinating Board (THECB). Although the Texas ERC maintains longitudinal data from the 1992-1993 school year onward, the project approved with the Texas ERC for this dissertation was permitted access to data from the 2002-2003 academic year onward. The Texas ERC is one of the largest and most complete public education information management systems in the world and provides researchers with opportunities to explore a variety of facets of public education.

In addition to having one of the largest collections of public education data, Texas is an interesting setting in which to explore the effects of market-based reforms upon student outcomes in STEM for other reasons. With respect to alternative teacher certification, the growth of alternative certification programs in Texas has far outpaced that growth in other parts of the country (Marder et al., 2020). Texas was also one of the first states to allow charter schools—legislation allowing for charter schools was first passed in

1995, just three years after Minnesota became the first state pass charter school legislation in 1992. That Texas has been a state in which alternative certification and charter schools have both thrived make it an ideal setting in which to study the effects of these reforms, particularly considering the rapid growth of these reforms in the rest of the nation. The lessons learned from data available in Texas can be used to inform education in policy in other parts of the country.

In addition to being an environment that is generally favorable to market-based education reforms, Texas has a large and varied student population served by urban, suburban, and rural school districts. Moreover, the student population in Texas closely resembles the student population in the United States as a whole. With such a large and varied student population in a variety of contexts that map comparatively well to the rest of the United States, insights gleaned from statewide analysis of education policy in Texas can be reasonably applied to other regions in the United States and used to inform federal education policy. With a strong charter sector and large number of alternative teacher certification programs, Texas is representative of what many other parts of the country could look like as these market-based reforms continue to expand and is therefore an important policy context in which to conduct research on education reform.

Chapter 2: Sector Differences in Student's Secondary STEM Course-taking Patterns and Post-Secondary Outcomes

INTRODUCTION

Charter schools are publicly funded schools that typically operate outside the domain of their local districts. Proponents maintain that independence from public school districts frees charter schools from bureaucratic regulations that limit schools' abilities to develop unique and innovative instructional models that meet students' needs. As the argument goes, charter schools' independence from local districts affords them opportunities to develop innovative educational paradigms within an otherwise stagnant educational system that is slow to change (Bierlein & Mulholland, 1994; Budde, 1988; Friedman, 2002). In recent decades, influential policy documents and media portrayals have contributed to popular support for charter schools by positioning them as schools that better serve socioeconomically disadvantaged students from historically marginalized ethnic populations and ultimately bridge achievement gaps that have persisted between disadvantaged students and their more advantaged peers (Goals 2000, 1994; Guggenheim, 2010; U.S. Department of Education, 2009). With broad popular and political support, the number of charter schools and the number of students enrolling in them have grown substantially since they first emerged in the early 1990's (NAPCS, 2018).

Due to the growth of charter schools, and the premises under which this growth has occurred, researchers have investigated the degree to which charter schools have impacted student outcomes, with results suggesting charter school impacts depend on context. In general, studies indicate that the effects of attending a charter school are positive for socioeconomically disadvantaged students living in urban settings, but that charter schools serving privileged student populations in other settings are associated decreases in students' scores on standardized exams (M. A. Clark et al., 2015; Gleason et al., 2010;

Tuttle et al., 2012). Another line of research suggests that the practices employed in no excuses[4] charter schools—specifically, extended instructional time, data-driven instruction, a rigid focus on test preparation, and strict behavioral standards—explain why these schools, which are typically located in urban settings and often serve socioeconomically disadvantaged student populations from historically marginalized ethnic minority populations, are more effective than non-charter schools at improving student outcomes, typically using performance on standardized exams as a proxy for student achievement (Curto & Fryer, 2014; Dobbie & Fryer, 2011, 2013, 2016).

One limitation of existing studies that have investigated differential student achievement by school sector (i.e., charter and non-charter public schools) is their predominant use of student performance on standardized exams as the outcome variable of interest instead of other student outcomes. That no excuses charter schools increase student performance on standardized exams to a greater extent than non-charter public schools is not altogether surprising given that no excuses charter schools often focus explicitly on preparing students for standardized exams.[5] For researchers and policy makers to have a

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[4] This subset of charter schools is typified by a "no excuses" approach to promoting student achievement. Working primarily with socioeconomically disadvantaged student populations, no excuses charter schools have high academic and behavioral standards and extended instructional time to promote student achievement. Some of the better-known charter school networks, such as KIPP and IDEA, adhere to this no excuses paradigm.

[5] Parenthetically, I reference my experience as a middle and high school science teacher at a no excuses public charter school in Washington, D.C. to illustrate the ways in which a rigid emphasis on student performance on high-stakes standardized exams manifested in instructional programming. Given that high-stakes assessments were administered in English language arts (ELA) and mathematics for all 6th, 7th, and 8th grade students, middle school students had more coursework in these two subjects than in any other subjects. During one particular academic year, students had four times more instructional time allocated for ELA and mathematics than instructional time allocated for science and social studies. As a science teacher, I found this organization of instruction problematic, as it limited students' access to subjects in which they could meaningfully apply what they learned in ELA and mathematics to instead focus on practicing rote skills that would improve their performance on standardized tests. In addition to allocating more instructional time for high-stakes subjects, the school also contracted with a company to administer practice standardized exams in ELA and mathematics periodically throughout the year. The motivation for these practice standardized exams was twofold. First, it gave students additional exposure to standardized exams; and second, these exams served to help teachers identify areas in which students needed extra support in

more well-rounded understanding of how charter schools affect student achievement, it is important for scholars to consider other indicators of student success. Toward that end, researchers have recently conducted studies investigating the effects of charter schools upon student enrollment in college (Davis & Heller, 2019; Dobbie & Fryer, 2016; Martinez et al., 2019; Place et al., 2019; Spees, 2019). As with student performance on standardized exams, students graduating from no excuses charter schools typically enroll in post-secondary institutions at higher rates than students from other schools.

The effects of no excuses charter schools upon students' post-secondary and labor market outcomes are nuanced, however. Despite the fact that graduates from no excuses charter schools have higher rates of college enrollment, Dobbie and Fryer (2016) find that labor market outcomes, as determined by students' average earnings, do not differ by sector. This nuance is at odds with the narratives championed by charter schools and charter school advocates. For example, IDEA public schools, a network of no excuses charter schools operating primarily in Texas, advertises that 100% of its graduates have been accepted to college since IDEA graduated its first class in 2007 (*IDEA Results*, n.d.). The "results" webpage for the Knowledge Is Power Program (KIPP), a no excuses charter network operating nationally, similarly advertises a high college acceptance rate as evidence of its success (*KIPP Results*, n.d.). KIPP reports that 80% of its graduates enroll in college and 35% complete college in four years, whereas the national college enrollment and 4-year graduation rates are 66% and 37%, respectively. That KIPP graduates enroll in college at a higher rate than the national average, yet have a 4-year college completion rate that is comparable to the national average brings into question the nature of the post-secondary outcomes achieved in charter schools, as does the finding that no excuses charter

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ELA and mathematics. After analyzing results from these exams, instruction would then be targeted such to give students extra practice in specific areas of need.

school graduates' high rate of college enrollment does not transfer to labor market outcomes.[6] Given the discrepant impacts of charter schools on various student outcomes beyond performance on standardized exams, it is important for research to investigate these discrepancies attending to the mechanisms that may be responsible for them.

While it is important for researchers to examine student outcomes other than standardized test performance, the call to do so with attention to the conditions within charter and non-charter schools that may be responsible for discrepant student outcomes underscores another limitation of extant literature on charter school impacts. Specifically, a wealth of literature exists identifying sector differences in student achievement, but most of this research has not sought to explore the reasons for these differences by investigating the practices within charter and non-charter schools that are potentially responsible for differential student outcomes (Berends et al., 2010; Berends & Donaldson, 2016; Preston et al., 2012). In light of this gap, Berends and Donaldson (2016) explored tracking in charter and non-charter schools to investigate whether different tracking practices explained differences in charter and non-charter student performance on mathematics

[6] Once again, I draw upon my experience as a science teacher at a "no-excuses" charter school in an effort to contextualize the difference between charter school students' college enrollment and college completion rates. Like KIPP, the school at which I worked billed itself as college-preparatory and boasted the statistic that more than 90% of its graduates enrolled in college. The college completion rate, however, was much lower (the exact value was shared at a professional development in-service I attended while working there, but I could not find this number when looking online). While I cannot pinpoint an exact reason for this disparity, plausible explanations come to mind. The emphasis on standardized-test performance over academic enrichment and rigor could mean that students did not develop the skills and aptitudes they needed for success at institutions of higher education. Therefore, while my school was able to leverage connections with institutes of higher education, thus providing pathways to college for students, the academic program offered to students did not prepare them to succeed at college. Another concern I had was the low retention of students. The charter school at which I worked served students in grades 6 to 12. Each year, between 90 and 100 new 6th grade students would enroll; however, the typical graduating class was fewer than 20 students. Therefore, the set of students graduating from the school and subsequently enrolling in college was a small subset of the students who originally began their studies at the school. This made me wonder whether the high college enrollment rate of our graduates was truly a result of the academic programming or instead an artifact of retaining students who were likely to enroll in college anyway.

exams. They found that although charter schools typically have higher percentages of socioeconomically disadvantaged students in higher tracks, this instructional organization does not translate to differences in math performance on standardized exams. Thus, these authors argue the instructional conditions in charter and non-charter schools are more alike than they are different.

In a prior study analyzing public education data in Texas, I extended upon the work from Berends and Donaldson (2016) by identifying differences in STEM course-offerings and course-taking patterns between charter and non-charter public schools (David, 2018; David et al., 2020). Results indicate that Texas charter schools are less likely than non-charter public schools to offer curricula tailored for students eligible for special education (SPED) services. Additionally, results suggest that relative to a STEM course-taking pattern identified as *college preparatory*, in which students take core STEM courses early in their high school trajectories and either elective or advanced courses later, charter school students are more likely to enroll in course-taking patterns in which they take more advanced courses (e.g., several AP STEM courses) or to enroll in course-taking patterns identified as basic (e.g., few advanced STEM courses). Given these results, I argue that charter schools in Texas cater to niche interests, whereas non-charter schools follow a mandate to serve all students.

In the present study, I draw upon results from prior work using students' secondary STEM course-taking patterns and charter school enrollment to predict their post-secondary achievement. Specifically, I address the following research questions:

1. Do secondary STEM course-taking patterns affect the probability of enrolling in college and do the effects of secondary STEM course-taking patterns differ by school sector?

2. Do students enrolled in different sets of secondary STEM course-taking patterns enroll in different kinds of post-secondary institutions (e.g., community college, 4-year public universities, or 4-year private universities)? Are these relationships affected by charter school enrollment?
3. How does the probability of obtaining a post-secondary degree in 4 years depend upon students' charter school enrollment and secondary STEM course-taking patterns? Does this relationship change for different kinds of post-secondary degrees (e.g., certificate, associate degree, bachelor's degree)? Do these relationships hold when considering the probability of students earning a post-secondary degree in a STEM discipline?

By addressing these research questions, I aim to provide insight into how sector differences in academic programming and instructional design contribute to differential student outcomes. However, to investigate sector differences in student outcomes, I argue it is important to move beyond examining sector differences in standardized exam scores and instead to investigate outcomes that are more meaningful for students. In addition, looking specifically at students' post-secondary outcomes provides insight into the degree to which charter and non-charter public schools are equipping students for success beyond the secondary level, whereas looking at students' scores on high-stakes standardized exams serves as a proxy for learning gains students obtain in high school. While I do not argue that student performance on standardized assessments is a trivial outcome, I maintain that one goal of public education is to equip students for success—broadly defined—beyond the confines of secondary education, be that civic participation, the capacity to pursue higher education, or a strong foundation upon which students can pursue their personal, professional, and academic interests. Therefore, in the school choice debate, it is necessary to consider these outcomes for policy makers and researchers to have a well-rounded idea of how the introduction of market-based principles to the public education system has affected student achievement and well-being writ large.

Literature Review

The literature germane to this study can be organized into two general strands. The first strand includes research investigating the effects of charter schools upon various post-secondary outcomes, including college enrollment, degree attainment, and labor-market participation. The second set of research explores how sector differences in instructional programming influence student outcomes. The research questions I pursue within this study are located at the intersection of these strands.

Charter Schools and Post-Secondary Outcomes

Comprehensive reviews on the relatively nascent research investigating post-secondary outcomes of charter school graduates reveals that findings are mixed (Cheng et al., 2017; Spees, 2019). One early study on the effects of charter schools upon post-secondary and other medium-term outcomes ("medium-term" refers to metrics measured shortly after high-school graduation) draws upon data from Promise Academy, a no excuses charter school located in the Harlem Children's Zone. From their analyses, Dobbie and Fryer (2015) report that students selected by randomized lottery to attend Promise Academy were more likely to graduate from high school and to enroll in college than students who were not admitted. In addition, they find that attending Promise Academy is associated with other positive outcomes, such as decreased incidences of incarceration and pregnancy. Dobbie and Fryer (2015) argue that their study contributes evidence to support the hypothesis that high-quality schools improve student achievement on tests and that improved student achievement on standardized tests is causally related to other longer-term outcomes. In their study, however, the authors do not evaluate the effects of enrolling in Promise Academy upon graduation from college, nor do they more substantively evaluate aspects of students' post-secondary academic trajectories, such as level of degree pursued or college major. The authors express optimism at the potential for high-quality, no excuses charter schools to yield positive outcomes for historically marginalized student populations, although they also discuss the need for additional research on the topic with analyses including broader sets of schools.

In a study following their 2015 analysis of Promise Academy, Dobbie and Fryer (2016) analyze data from Texas to investigate the effects of charter schools upon a variety of student outcomes. They find that charter schools, on average, do not have a statistically significant effect on students' standardized test score gains, a finding that has also been replicated in analyses of charter schools in other parts of the country (M. A. Clark et al., 2015; Gleason et al., 2010; Tuttle et al., 2012). Despite the fact that there is no average effect of charter schools on student test score gains, Dobbie and Fryer (2016) report no excuses charter schools in Texas increase students' scores on standardized exams, which is consistent with the results from studies on no excuses charter schools in New York City (Dobbie & Fryer, 2011, 2013) and Washington, D.C. (Curto & Fryer, 2014). In addition to improving student test scores on standardized assessments, students enrolled in no excuses charter schools in Texas were found to graduate with higher rates and enroll in 4-year colleges at higher rates than students enrolled non-charter public schools and charter schools that were not no excuses (Dobbie & Fryer, 2016). Dobbie and Fryer do not evaluate the effect of charter schools upon degree attainment in their study; however, results suggest there are no sector differences in labor market outcomes as measured by graduates' ultimate earnings (Dobbie & Fryer, 2016). As such, the effects of charter schools on short- and medium-term outcomes (test score gains and college enrollment, respectively, for example) do not translate to longer-term outcomes like earnings, necessitating that researchers and policy-makers temper some of the enthusiasm for charter schools that are highly-effective at improving these specific student outcomes.

To estimate the causal effects of charter middle schools upon students' test score gains, a set of several studies analyzed data from a nationally representative set of over-subscribed charter middle schools and took advantage of the randomized lottery admissions process (M. A. Clark et al., 2015; Gleason et al., 2010; Tuttle et al., 2012). Using data from the same set of schools, Place et al. (2019) explore how attending a middle charter school affected students' college enrollment and degree attainment. Their results indicated that charter school attendance did not have any statistically significant effects upon the likelihood of students either enrolling in college or obtaining a degree (associate, bachelor's, or certificate) by the conclusion of the study period. Moreover, these trends were independent of a charter school's demonstrated ability to improve student performance on standardized exams. That charter schools effective at improving student performance on standardized exams do not have any appreciable impact upon longer-term student outcomes, such as college enrollment and degree attainment, is consistent with the disparities in charter schools' effectiveness in improving student performance on exams without affecting students' labor market outcomes reported in Dobbie and Fryer (2016).

In contrast to results that suggest the positive effects of charter schools upon student outcomes on standardized exams do not translate to longer-term outcomes (Dobbie & Fryer, 2016; Place et al., 2019), results from an analysis of Florida charter schools suggests that students who attended a charter school were more likely to persist through college and to have higher earnings by their mid-20's than comparable students in non-charter schools. A separate analysis of the Noble Charter network in Chicago suggested that the benefits of enrolling in this charter network extended beyond increases in standardized exam performance (Davis & Heller, 2019). Graduates from Noble Street College Prep were found to have higher rates of college enrollment and persistence, and graduates from other schools in the Noble Charter network were also found to have higher rates of college enrollment than graduates from comparable schools. Gwynne and Moore (2017) also analyze post-secondary outcomes of charter school graduates from Chicago public schools, with results suggesting that charter schools were responsible for increased college enrollment and persistence among high school graduates. However, when compared to other students enrolled in college, charter school graduates did not have statistically significant differences in their persistence.

In a study estimating the causal effects of Boston charter schools upon students' post-secondary outcomes, Angrist and colleagues (2016) report that although charter schools do not improve graduates' rates of college enrollment, charter school graduates are more likely to enroll in 4-year institutions as opposed to 2-year institutions. In addition, charter schools positively affect student performance on the SAT and rate of taking Advanced Placement (AP) exams, suggesting that these charter schools are better at preparing students for college. Similar findings come from a separate study of charter schools in Los Angeles that found charter school students outperformed students in non-charter public schools on metrics of college readiness, including performance on AP exams (Adzima, 2017).

Instructional Conditions in Charter Schools

Charter school researchers investigating sector differences in student outcomes—from student performance on standardized exams to college enrollment and persistence—have focused largely on identifying the direction and magnitude of sector differences but have not paid much attention to the reasons for these differences. Several scholars have underscored the need for charter school researchers to move beyond a general fixation on differential outcomes by sector and instead focus their efforts on investigating the mechanisms and underlying conditions within charter and non-charter public schools that may explain these differences. Extant research has investigated how staffing differences (Cannata & Penaloza, 2012; Carruthers, 2012) and differences in instructional organization (Berends et al., 2010; Berends & Donaldson, 2016; David, 2018) explain sector differences in student outcomes.

In their study investigating how sector differences in instructional organization impact student performance on mathematics exams, Berends and Donaldson (2016) find that socioeconomically disadvantaged students from underrepresented ethnic minority populations at charter schools are more likely than their peers in non-charter public schools to enroll in advanced tracks. Despite this difference, however, enrolling in a more advanced academic track at a charter school is not associated with statistically significantly different gains in math achievement than enrolling in a similar track at a non-charter public school. Given these findings, Berends and Donaldson (2016) argue that the instructional conditions in charter schools are not substantively different than those in non-charter schools, as gains related to academic tracks are similar between the two sectors.

In a prior study extending upon the work of Berends and Donaldson (2016), I analyzed secondary STEM course-offerings and course-taking patterns in Texas charter and non-charter public schools (David, 2018; David et al., 2020). I found that charter schools were less likely than non-charter schools to offer STEM courses tailored specifically for students who qualify for special education services. In addition, students in non-charter public schools were more likely to enroll in STEM-course sequences in which they took core STEM courses in the early stages of high school and either elective or advanced courses (such as Advanced Placement and International Baccalaureate courses) in their final years of high school. By contrast, students in charter schools were more likely than non-charter school students to enroll in sets of courses that were more basic, consisting of core courses with few electives, or more advanced, consisting of a higher average number of upper-level STEM courses. While these results point to important differences in the instructional organization of STEM coursework in charter and non-charter schools, it is also important evaluate how these differences impact student outcomes.

As Dobbie and Fryer (2016) posit, one plausible explanation for the fact that no excuses charter schools are effective at improving standardized test scores and college enrollment without appreciably affecting longer-term outcomes (earnings) is that these schools have found ways to improve students' test-taking abilities at the expense of enhancing students' skills and aptitudes in other areas that are important for success in the labor market. Drawing from prior results on STEM course-offerings and students' STEM course-taking patterns in charter and non-charter schools provides a potentially fruitful way to explore this hypothesis. Specifically, if students enrolled in comparable sets of courses from charter and non-charter schools have different post-secondary outcomes, this may suggest that the broader benefits afforded to students by virtue of engaging in a curricular set are not the same across sector, thus affecting students' engagement and persistence at the post-secondary level. The goals of this study align with the broader mandate to identify the mechanisms within charter and non-charter schools that are responsible for differential outcomes by examining whether or not course-taking in charter and non-charter public schools is related to students' post-secondary outcomes.

DATA AND SAMPLE

To investigate how students' STEM course-taking patterns in charter and non-charter public schools impact their post-secondary outcomes, this study analyzes administrative data available through the Texas Education Research Center (ERC). The Texas ERC has student- and teacher- level data for all public schools in Texas from 1993 onward. Specifically, data available in the ERC include demographic, certification, and employment data for all public school teachers in Texas; demographic, enrollment, and accountability data for public school students in Texas; and organizational data at the district and campus levels for all public education institutions. In addition, the ERC maintains post-secondary data for all students who graduate from Texas public secondary schools and for any students enrolled in a Texas institution of higher education, including 4-year public and private universities and community colleges. Post-secondary data include information on students' enrollment, major, performance, and graduation.

In order to characterize students' course-taking patterns, a cohort of students starting the 9th grade for the first time in the 2011-2012 school year is followed over four consecutive years (to the 2014-2015 school year) because this is the typical amount of time it takes for students to complete high school in the United States. ERC data include unique course identifiers that indicate the subjects of the courses in which students are enrolled (e.g., physics, algebra I). Student demographic, attendance, and exit data are merged onto their course enrollment data over the duration of the four-year period.

Course enrollment and demographic data are subsequently merged onto graduation data for students who graduate from high school in the 2014-2015 school year. Not all students starting in the 9th grade in the 2011-2012 school year graduate in four years. However, by restricting the data set to students for whom it is possible to track their entire secondary course-taking and who then graduate at the end of the four year period during which course-taking data are collected makes it possible to analyze how these course-taking patterns relate to post-secondary outcomes. The post-secondary outcomes of students who took either more or less time to complete high school may be affected by unique factors that do not reflect their course-taking patterns at the high school level. For example, it is possible that a student who completed high school in five, rather than four, years may have received support during that additional year that would affect that students' post-secondary enrollment and persistence.

At the secondary level, students may transfer between schools, and thus their course-taking is distributed over multiple campuses. When students transfer between schools, a dummy course indicator is added to the course enrollment data set to indicate whether or not that student transferred from or to a given campus and the year in which that transfer occurred. A student's time at a given campus is weighted by 0.25 for each year spent at that campus, and if a student attends two or more campuses in a given year, the yearly weight is divided evenly among those campuses.

At the post-secondary level, binary indicators are generated to indicate whether or not a student enrolled in a post-secondary institution in the year following high school graduation, earned a post-secondary degree within 4 years of high school graduation, and earned a post-secondary degree in STEM within 4 years of high school graduation. In addition to binary indicators, there are also categorical variables for post-secondary institution type (e.g., private four year, public four year, community college, or out of state university), degree type/status at 4 years (e.g., bachelor's, associate, certificate, dropped-out, or continued enrollment without a degree), and STEM degree type/status at 4 years (with an extra category indicating that students earned a non-STEM post-secondary degree).

In addition to restricting the data set to students starting the 9th grade in 2011 and graduating from high school in 2015, students who exit a school for reasons other than transfer or dropping out (e.g., such as moving to another state, where continued course-taking patterns are no longer available in the data set) and students enrolled in schools specifically tailored for students facing criminal disciplinary action are removed from the data set. Including students with atypical reasons for exiting the school system could potentially bias results, as these students were not observed during a period in which they had a potential to enroll in four years of secondary STEM courses. Students enrolled in disciplinary alternative education programs are often facing criminal charges and therefore do not have the same access to same sets of courses as students in other schools. These schools are characteristically not schools of choice and should therefore not be included in a study exploring the effects of school choice upon students' post-secondary attainment.

ANALYTIC METHODS

Analysis proceeds in two stages. First, STEM course-taking patterns are identified through social network analysis and community detection, following the same procedure I used to identify sector differences in course-offerings and course-taking patterns in prior work (David, 2018; David et al., 2020). Students' secondary STEM course-taking patterns are then used as predictor variables in a set of logistic and multinomial logistic models that predict how enrolling in specific sets of courses in a charter or non-charter public school either increase or decrease the probability of a student achieving various post-secondary outcomes.

Identifying Course-taking Patterns through Social Network Analysis

Social network analysis and community detection are used to identify prominent STEM course-taking patterns over the four years following students' initial enrollment in the 9th grade. In contrast to descriptive statistics that show how certain characteristics are distributed among a population of interest, social network analysis allows researchers to evaluate the relationships between actors in the population of interest (Borgatti & Ofem, 2010; Carolan, 2014). Sociograms are tools with which it is possible to visualize and analyze the relationships between actors in a network. A sociogram consists of nodes, which are used to represent individual agents (such as schools or teachers), and edges exist between two nodes if they share a common attribute or have some other commonality, like membership in the same friend group.

Networks in which students are represented by nodes and edges between them represent that two students are enrolled in the same STEM course in the same year are used to identify STEM course-taking patterns in Texas charter and non-charter public schools. Since certain groups of students are often in several STEM courses together throughout the duration of high school, edges between nodes are weighted by the number of courses in which two individual students are commonly enrolled. To identify groups of students that are closely related due to their mutual enrollment in a high number of STEM courses, a community detection algorithm is applied to the network such to maximize the modularity of the network. Modularity quantifies the difference between the fraction of edges in a network that fall within that network's community structure and the expected fraction of networks that would fall within that community structure had the same number edges between nodes been randomly assigned.

Mathematically, modularity, Q, is given by Equation (1):

$$Q = \frac{1}{2m}\sum_{ij}\left(A_{ij} - \frac{k_i k_j}{2m}\right)\delta(c_i, c_j) \tag{1}$$

In Equation (1), A_{ij} gives the weight of the edge connecting nodes i and j, k_i represents the sum of the weights of the edges connected to node i, m is equal to $\frac{1}{2}\sum_{ij} k_i k_j$ and gives the sum of the edge weights in the entire graph, and $\delta(c_i, c_j)$ is Kronecker's delta function, which is equal to one when c_i and c_j are equal (indicating that nodes i and j belong to the same community) and zero otherwise. When the modularity of a network is maximized, the optimal underlying community structure has been identified.

A community within a network is defined as a set of nodes that are densely connected to one another, but loosely connected to nodes outside of the network (Clauset et al., 2004; Fortunato, 2010; Newman, 2006; Newman & Girvan, 2004). Networks of students are constructed at the campus level, and communities represent groups of students within each campus enrolled in similar sets of STEM courses. Within each of the approximately 1,500 campuses included in this study, it is possible for students to belong to one of several communities. The sets of courses connecting different groups of students within a school comprise the different course-taking patterns available in that school. To differentiate these course-taking patterns, k-means clustering is used. In the k-means clustering algorithm, *N* data points with a vector of attributes, $x_i^{(j)}$, are partitioned into *k* groups such that the within group sum of squares of each group, *j*, is minimized (MacQueen, 1967). Mathematically, this is done by minimizing the objective function, *J*, given by Equation (2):

$$J = \sum_{j=1}^{k} \sum_{i=1}^{n} \left\| x_i^{(j)} - c_j \right\|^2 \tag{2}$$

As with prior analyses (David, 2018; David et al., 2020), *k* is set to 6 due to parameters of the system, meaning the communities identified across the set of schools analyzed in this study are categorized into six distinct groups based upon the similarity of the attributes of the groups (e.g., average number of STEM course completed, average percentage of students enrolling in advanced coursework, average percentage of students transferring, etc.).

Following conventions set forth in David (2018) and David et al. (2020), the six categories of course sets are: *advanced*, *basic*, *college preparatory*, *exit*, *SPED*, and *transitional*. The most common set of STEM courses is the college preparatory set, in which students enroll in several core STEM courses in the beginning half of high school and subsequently enroll in either elective or advanced STEM courses toward the end of high school. The percentage of students taking advanced courses in the *advanced* course set is higher than the number of students doing so in the *college preparatory* set, and students enrolled in a *basic* course set typically take the core STEM courses followed by few non-advanced electives. The *SPED* course set is characterized by the high percentage of students enrolled in STEM courses tailored for students who qualify for special education. In both the *exit* and *transitional* course sets, high percentages of students transfer from one school to another; however, the *exit* course set is characterized by the highest proportion of students dropping out of high school.

Statistical Analysis to Determine the Probability of Post-Secondary Outcomes

The post-secondary outcomes of interest are either binary or categorical, so logistic and multinomial regression models are constructed to analyze how course-taking in charter and non-charter public schools influences the probabilities of students achieving these outcomes. There are two primary binary outcomes of interest: a) whether or not high school graduates enroll in college within one year of high school graduation; and, b) whether or not high school graduates earn a degree within four years of their high school graduation. The logistic models specified to analyze each of these binomial outcomes are given by Equations (3) and (4), respectively:

$$log\left(\frac{p_i}{1-p_i}\right) = \beta_C C_i + \beta_P Crs_i + \beta_{Int} Crs_i C_i + \beta_X \boldsymbol{X_i} + Camp_{j[i]} \tag{3}$$

In Equation (3), p_i is the probability that student i enrolls in college within one year of graduation, C_i is a binary variable indicating whether or not student i attended a charter school, Crs_i is a categorical variable indicating the STEM course-taking pattern in which student i enrolled, $\boldsymbol{X_i}$ is a vector of demographic characteristics (including race, gender, eligibility for free and reduced lunch as a proxy for economic disadvantage, designation as Limited English Proficient (LEP), gifted, or SPED), and $Camp_{j[i]}$ represents a categorical variable for campus j in which student i was enrolled. Campus effects are included in order to compare students within campuses, and specifications of models include the campus term included both as fixed effects and a random effects terms.

Equation (4) is specified to predict the probability of students earning a degree within four years of their high school graduation. It is nearly identical to Equation (3); however, this model includes a variable for the type of post-secondary institution that student i attended (represented by I_i) and a flag to indicate whether or not student i graduated from the same institution in which he or she initially enrolled, M_i:

$$log\left(\frac{p_i}{1-p_i}\right) = \beta_C C_i + \beta_P Crs_i + \beta_{Int} Crs_i C_i + \beta_I I_i + \beta_M M_i + \beta_X \boldsymbol{X_i} + Camp_{j[i]} \quad (4)$$

In addition to modeling how enrolling in certain sets of STEM courses at charter and non-charter public schools in Texas are related to the probabilities of enrolling in post-secondary institutions and earning a post-secondary degree within 4 years, it is also of interest to investigate how STEM course-taking in Texas charter and non-charter public schools influences the probabilities of students enrolling in certain *kinds* of post-secondary institutions (e.g., community college, public 4-year universities, or private 4-year universities) and earning certain *kinds* of post-secondary degrees (e.g., certificate, associate degree, or bachelor's degree). Multinomial regression models specified by Equations (5) and (6) are used to investigate these questions:

$$log\left(\frac{p_i^{\alpha}}{p_i^{ref}}\right) = \beta_C C_i + \beta_P Crs_i + \beta_{Int} Crs_i C_i + \beta_X \boldsymbol{X_i} + Camp_{j[i]} \tag{5}$$

In Equation (5), p_i^{α} gives the probability of student i enrolling in an institution of higher education of type α (where α indicates private 4-year university, public 4-year university, community college, or an out-of-state university). p_i^{ref} is the reference and is taken to be the probability of a student not enrolling in any post-secondary institution. The predictor variables in Equation (5) are identical to those specified in Equation (3).

As with the logistic models, a separate multinomial specification is constructed to evaluate the probability of earning different *kinds* of post-secondary degrees, as described by Equation (6). This model is employed to evaluate the kinds (e.g., bachelor's or associate) of post-secondary degrees students earn in general and in STEM disciplines.

$$log\left(\frac{p_i^{\alpha}}{p_i^{ref}}\right) = \beta_C C_i + \beta_P Crs_i + \beta_{Int} Crs_i C_i + \beta_I I_i + \beta_M M_i + \beta_X \boldsymbol{X_i} + Camp_{j[i]} \tag{6}$$

Here, p_i^{α} gives the probability of student i having status α four years after graduating from high school, where α indicates a student earned a bachelor's degree, associate degree, post-secondary certificate, or is still enrolled in an institution of higher education. In the model specified for STEM degrees, α indicates a STEM bachelor's degree, STEM associate degree, STEM certificate, non-STEM degree, or continued enrollment in an institution of higher education. In both models, p_i^{ref} is the reference category representing the probability that a student is no longer enrolled in a post-secondary institution and has not earned a post-secondary degree by the 4th year following high school graduation. In addition, the multinomial models for post-secondary degree attainment include a binomial variable indicating whether or not student i graduated from the same institution type in which he or she first enrolled, M_i, and a categorical variable representing the type of institution from which the student earned a degree, I_i.

Three separate specifications of the multinomial logistic regression models given by Equations (5) and (6) are run, one with fixed campus effects, another with random campus effects, and a third with no campus effects. Running three different variants was primarily exploratory, and random effects models provide the most reliable estimates and are therefore described in the results section.

Model specifications with campus effects are run using the Begg and Gray approximation (Begg & Gray, 1984), in which individual logistic models are computed for each contrast. Estimating models using the Begg and Gray approximation circumvents the computational difficulty of estimating a single multinomial model with campus level effects included. Since multinomial regression models use the Begg and Gray approximation, sub-setting the original data set for each contrast results in fewer observations being analyzed for each model. Moreover, relatively few students who enroll in the *exit*, *transitional*, and *SPED* secondary STEM course sets achieve the post-secondary outcomes of interest. Thus, to include these students in models and investigate the statistical effect of their course-taking pattern upon post-secondary outcomes, these three sets of secondary STEM course taking patterns are collapsed into one category (labeled *other* in multinomial output).

RESULTS

The first set of models predicts the likelihood of a student enrolling in a post-secondary institution as a function of that student's enrollment in a charter school, secondary STEM course-taking pattern, the interaction of these two variables, and demographic covariates. Two specifications of the logistic model given by Equation (3) are run, one including fixed campus effects and the other including random campus effects. The coefficients for these models are provided in Table 1, and a Sankey diagram giving the proportion of students from charter and non-charter schools enrolling in post-secondary institutions disaggregated by high school course-taking pattern is provided in Figure 1.

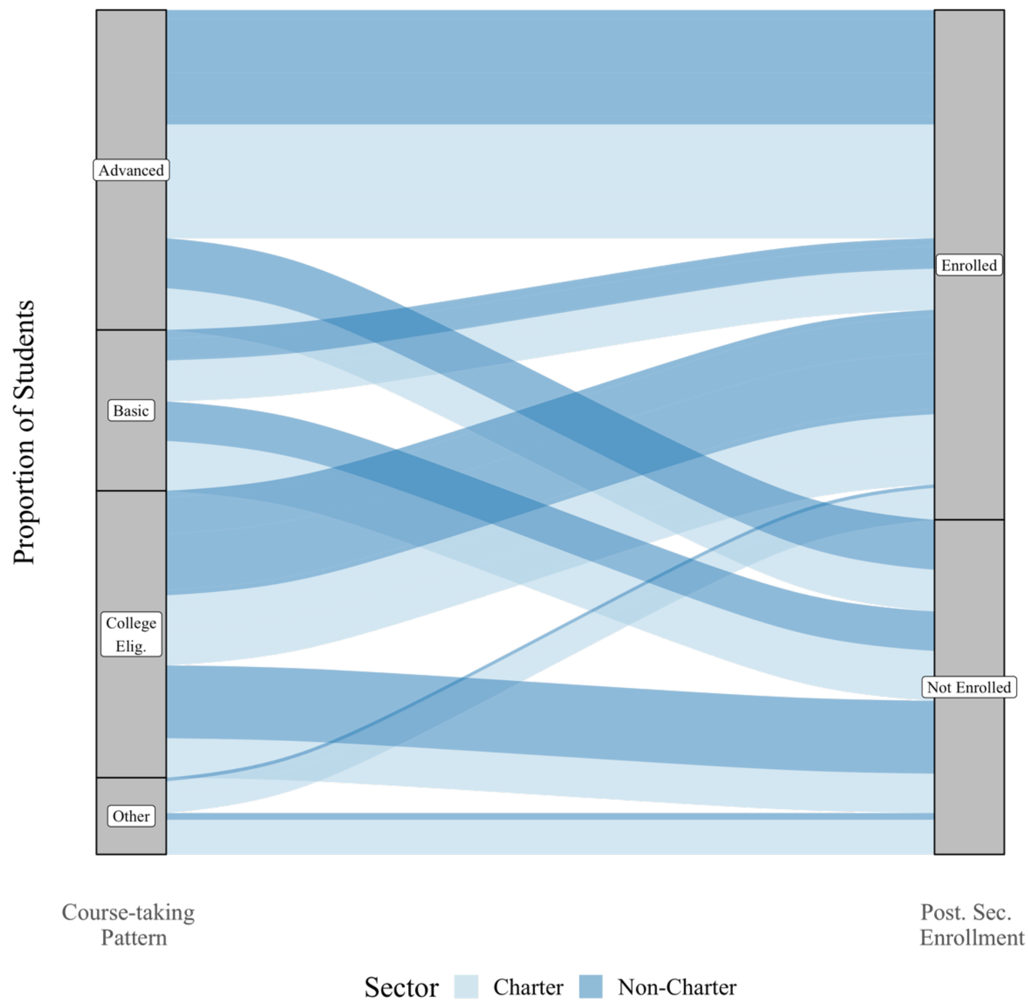

Figure 1. Sankey diagram giving the proportion of students enrolling in post-secondary institutions by secondary STEM courses and sector.

Exponentiating the coefficients in Table 1 gives the associated change in the odds of a student enrolling in a post-secondary institution relative to not enrolling in any. For example, the random effects model indicates that, compared to students attending a non-charter public schools, attending a charter school is associated with 22% increase in the likelihood of a student enrolling in a post-secondary institution within one year of his or her graduation from high school as opposed to not enrolling at all. According to the fixed effects model, a charter school student enrolling in a basic set of STEM courses has 58% higher odds of enrolling in a post-secondary institution within one year of graduating from high school as opposed to not enrolling at all than a student enrolling in a basic set of STEM courses at a non-charter public school.

Table 1. Coefficients from models predicting the likelihood of a student enrolling in a post-secondary institution within one year of graduating from high school.

	Fixed Campus Effects			**Random Campus Effects**		
Coefficients	**Est**	**SE**	**Sig**	**Est**	**SE**	**Sig**
Intercept	0.4	-0.37		0.65	-0.02	***
Charter	0.54	-0.94		0.20	-0.09	*
Adv. Courses	0.37	-0.01	***	0.36	-0.01	***
Basic Courses	-0.61	-0.02	***	-0.6	-0.02	***
Exit Courses	-1.31	-0.14	***	-2.15	-0.23	***
SPED Courses	-1.76	-0.26	***	-1.89	-0.29	***
Trans, Courses	-0.54	-0.04	***	-0.71	-0.06	***
Charter, Adv.	-0.08	-0.14		0.18	-0.11	
Charter, Basic	0.46	-0.15	**	0.04	-0.13	
Charter, Exit	1.27	-0.6	*	0.61	-1.92	
Charter, Trans.	0.08	-0.17		-0.41	-0.24	.
Asian	0.37	-0.03	***	0.36	-0.03	***
Black	0.38	-0.02	***	0.35	-0.02	***
Latinx	-0.17	-0.01	***	-0.17	-0.01	***
Female	0.41	-0.01	***	0.42	-0.01	***
Econ. Dis.	-0.7	-0.01	***	-0.71	-0.01	***
Gifted	0.69	-0.02	***	0.69	-0.02	***
LEP	-1.18	-0.03	***	-1.22	-0.03	***
SPED	-0.79	-0.02	***	-0.77	-0.02	***

*** $p < 0.01$; ** $p < 0.01$, * $p < 0.05$, . $p < 0.10$

Of note, the charter school effect is not statistically significant in the fixed effects model but only in the random effects model. The coefficients for enrolling in advanced and basic courses have similar magnitudes in both models; however, the coefficients for enrolling in SPED courses or course sets associated with exit or transition increase in magnitude in the random effects model. The coefficients for course-taking patterns are all significant, but their interaction with school type are only significant for the basic and exit course sets in the fixed effects model.

Table 2. Coefficients from model predicting the log odds of a student earning a post-secondary degree or certificate within 4-years of high school graduation.

Coefficients	Est	SE	Sig
Intercept	-1.12	0.02	***
Charter	-0.08	0.1	
Adv. Courses	0.27	0.02	***
Basic Courses	-0.4	0.02	***
Exit Courses	-0.22	0.28	
SPED Courses	-0.29	0.61	
Trans, Courses	-0.75	0.07	***
Charter, Adv.	-0.34	0.13	**
Charter, Basic	0.22	0.17	
Charter, Exit	1.48	0.84	.
Charter, Trans.	0.74	0.21	***
Asian	0.19	0.03	***
Black	-0.64	0.02	***
Latinx	-0.18	0.02	***
Female	0.5	0.01	***
Econ. Dis.	-0.35	0.02	***
Gifted	0.45	0.02	***
LEP	-0.06	0.06	
SPED	-0.37	0.04	***
Private 4-Year	0.38	0.02	***
Public 4-Year	-0.07	0.01	***
Same Inst. Type	0.84	0.01	***

*** $p < 0.01$; ** $p < 0.01$, * $p < 0.05$, . $p < 0.10$

Coefficients from the model predicting the likelihood of a student earning a post-secondary degree within 4-years of his or her high school graduation are provided in Table 2. A Sankey diagram giving the proportion of students who either earned a degree of are still enrolled 4-years following high-school graduation by sector, secondary STEM course enrollment, and post-secondary institution type is provide in Figure 2. For this model and all subsequent models, only models including random effects coefficients for campus are reported, as they provided more reliable estimates and make more sense theoretically. Campus-level effects are not independent of other covariates, but are related to other factors, such as campus wide demographic composition and school type. In addition, the effect of a campus is unlikely to be the homogenous for all students—particularly since several different course-taking patterns are available to students within a single campus—so random effects coefficients are more appropriate for the models included in this study.

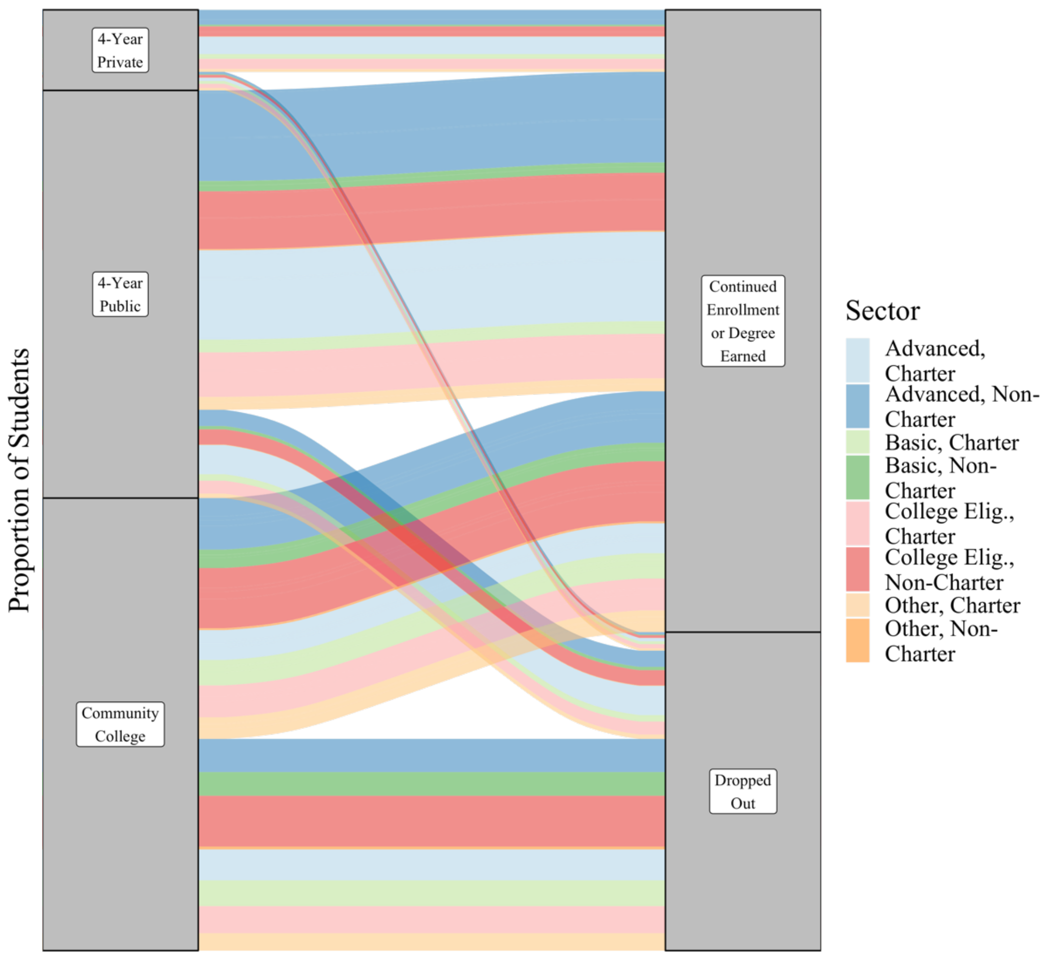

Figure 2. Proportion of students with continued post-secondary enrollment or degree attainment within 4-years of high school graduation by post-secondary institution type. Color represents sector and secondar STEM course taking.

As indicated in Table 2, attending a charter school is not associated with any statistically significant difference in the likelihood of earning a post-secondary degree within 4-years of high school graduation as compared to attending a non-charter school. Statistically significant differences in the odds of earning or continuing to pursue a post-secondary degree 4 years after high school graduation are found for students enrolling in an advanced STEM course set (31% increase in odds), basic STEM course set (33% decrease in odds), and transitional STEM course set (53% decrease in odds). Interestingly, students enrolling in a private 4-year university experienced an increase in the odds of graduating in 4 years as do students who graduate from the same type of institution in which they originally enrolled. Students in public 4-year universities have a statistically significant 6% decrease in the odds of earning a degree within 4-years of graduation from high schools. Statistically significant interactions are also found: charter school students enrolling in advanced STEM course sets are 28% less likely than non-charter public school students enrolling in similar sets of STEM courses of earning a post-secondary degree within 4-years. The interaction between school type and transitional sets of courses suggests that charter school students who transition do not experience as much of a decrease in the odds of earning a post-secondary degree within 4-years as students who transition in or out of non-charter public schools. Finally, the model results indicate that relative to students identifying as White, students identifying as Black and Latinx have statistically significant lower odds of earning a post-secondary degree within 4 years and students identifying as Asian have statistically significant higher odds of earning a post-secondary degree within 4 years. Further, students identified as economically disadvantaged are less likely than their economically advantaged peers to earn a post-secondary degree within 4 years of graduating from high school.

To investigate sector differences in the types of post-secondary institutions in which high school graduates enrolled, a multinomial logistic regression was constructed to compute the relative probability of a student enrolling in a certain type of post-secondary institution as a function of that student's enrollment in charter schools, set of STEM courses, and the interaction between the two. The coefficients from these multinomial regressions are provided in Table 3. Exponentiating the coefficients gives the relative probability of a student enrolling in the indicated type of post-secondary institution relative to not enrolling in any post-secondary institution.

Table 3. Regression output from multinomial logistic model predicting the likelihood of high school graduates enrolling in certain types of post-secondary institutions.

	Community College			**Public 4-Year University**			**Private 4-Year University**			**Out-of-State Institution**		
Coefficients	**Est**	**SE**	**Sig**	**Est**	**SE**	**Sig**	**Est**	**SE**	**Sig**	**Est**	**SE**	**Sig**
Intercept	-0.07	0.02	***	-0.34	0.03	***	-2.12	0.04	***	-2.31	0.04	***
Charter	-0.07	0.11		0.28	0.13	*	0.82	0.18	***	0.75	0.21	***
Adv. Courses	0.01	0.02		0.70	0.02	***	0.58	0.03	***	0.66	0.03	***
Basic Courses	-0.41	0.02	***	-1.22	0.03	***	-1.02	0.05	***	-0.98	0.06	***
Other Courses	-0.82	0.06	***	-1.45	0.12	***	-1.61	0.30	***	-1.47	0.32	***
Charter, Adv.	0.04	0.14		0.17	0.15		0.11	0.23		0.72	0.25	**
Charter, Basic	0.14	0.15		0.46	0.2	*	0.04	0.31		0.18	0.36	
Charter, Other	0.18	0.26		-0.26	0.40		-0.76	0.89		-2.03	1.70	
Asian	0.16	0.04	***	0.62	0.03	***	-0.24	0.07	***	-0.75	0.07	***
Black	0.17	0.02	***	0.5	0.02	***	0.53	0.04	***	0.55	0.04	***
Latinx	0.02	0.01		-0.41	0.02	***	-0.37	0.03	***	-0.58	0.04	***
Female	0.35	0.01	***	0.49	0.01	***	0.48	0.02	***	0.45	0.03	***
Econ. Dis.	-0.48	0.01	***	-0.95	0.02	***	-1.16	0.03	***	-1.33	0.04	***
Gifted	-0.16	0.02	***	1.16	0.02	***	1.00	0.03	***	0.90	0.04	***
LEP	-0.94	0.03	***	-2.51	0.08	***	-3.32	0.30	***	-2.07	0.22	***
SPED	-0.42	0.02	***	-2.11	0.05	***	-1.59	0.09	***	-1.39	0.09	***

*** $p < 0.01$; ** $p < 0.01$, * $p < 0.05$, . $p < 0.10$

A Sankey diagram, provided in Figure 3, shows the proportions of students taking specific STEM course sets in secondary charter and non-charter schools who ultimately enroll in different types of post-secondary institutions. Exponentiated coefficients of the main effects (enrollment in a charter school, secondary STEM course sets, and their interaction) from Table 3 are displayed in Figure 4, giving the associated change in odds of enrolling in a particular type of post-secondary institution relative to not enrolling.

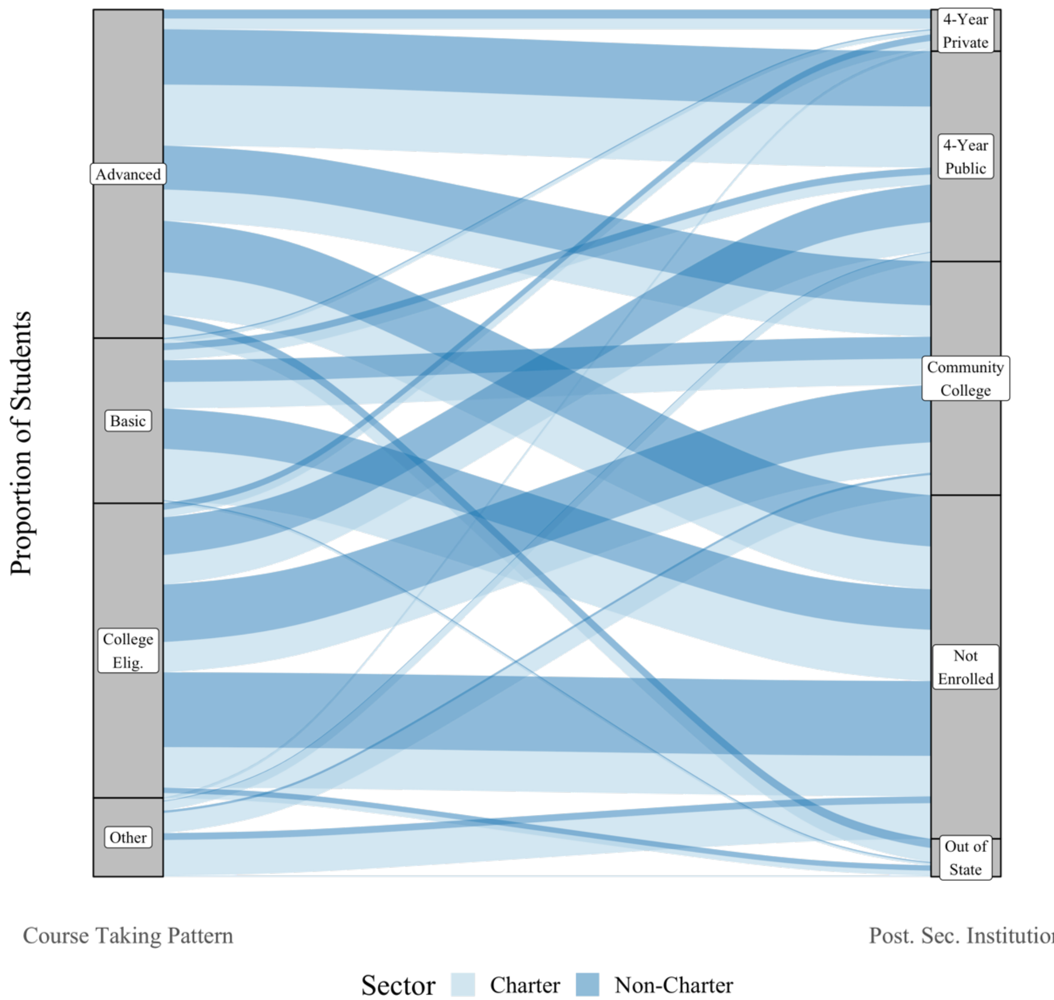

Figure 3. Sankey diagram showing the proportion of charter and non-charter school students enrolling in different types of post-secondary institutions from secondary STEM course enrollment.

As indicated in the output, charter schools are not associated with a statistically significant difference in the probability of a student enrolling in a community college; however, attending a charter school is associated with statistically significant increases in the likelihood of a student enrolling in a public 4-year university, private 4-year university, or out-of-state post-secondary institution. The interaction between charter schools and enrollment in advanced STEM course sets is associated with increased odds of enrolling in an out-of-state post-secondary institution, and the interaction between charter schools and enrollment in basic STEM course sets is associated with an increased probability of enrolling in a public 4-year university. All other interactions between charter schools and course offerings are not statistically significant.

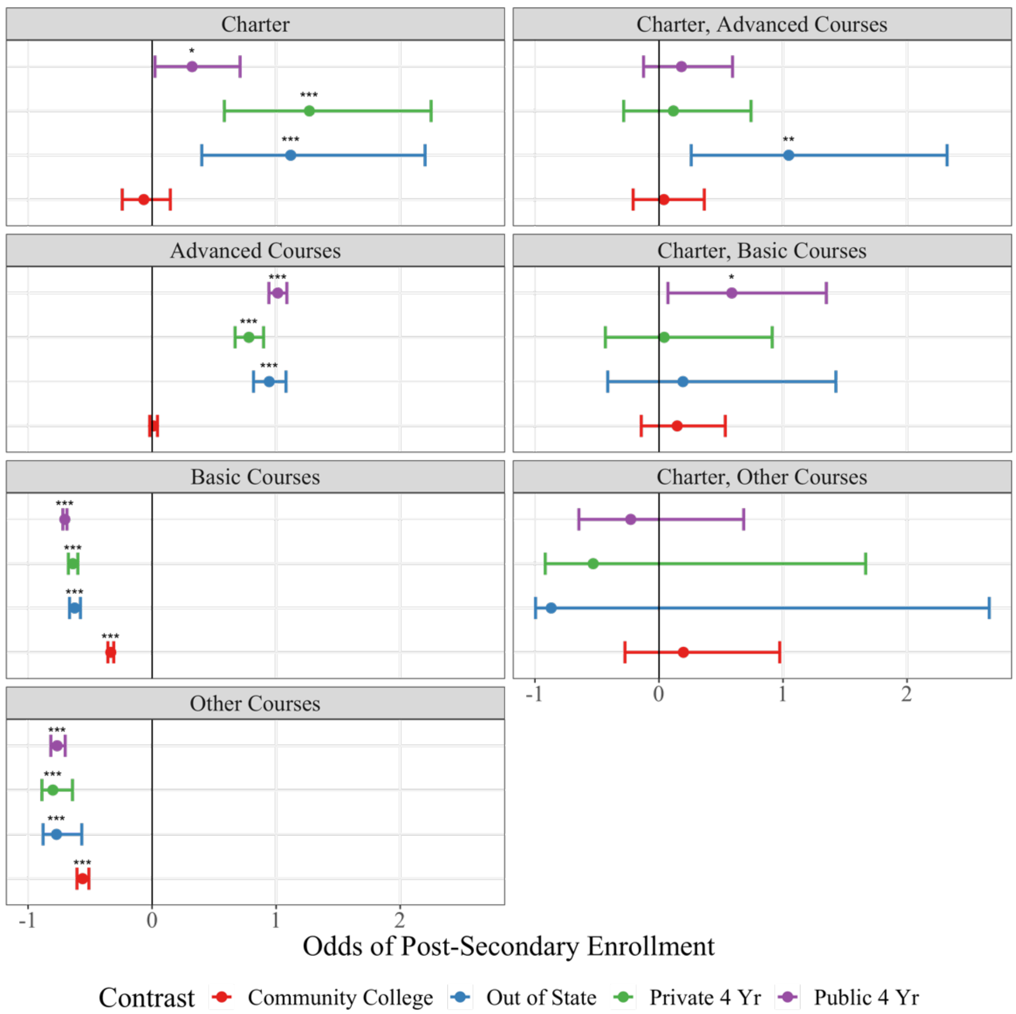

Figure 4. Change in odds of enrolling in various types of post-secondary institutions associated with charter attendance and secondary STEM course-taking.

Individual course-taking patterns, however, are associated with differences in the probability of enrolling in different types of institutions, and these trends hold across all contrasts. Enrolling in an advanced set of STEM courses is associated with increases in the likelihood of enrolling in public and private 4-year universities in addition to out-of-state post-secondary institutions relative to students enrolled in a college preparatory set of STEM courses. By contrast, enrolling in basic or other sets of STEM courses are associated with decreases in the probability of enrolling in any type of post-secondary institution relative to students who enrolled in a college preparatory set of STEM courses.

The next multinomial logistic regression model predicts the relative probabilities of students achieving different post-secondary outcomes 4 years following their high school graduation (e.g., earning a certificate, associate degree, bachelor's degree, or continued enrollment) relative to dropping out (as determined by students who neither earned a post-secondary degree or certificate nor continued to be enrolled 4 years after their graduation from high school). These probabilities are modeled as a function of enrollment in a charter school, enrollment in different STEM course sets, the interaction of these two variables, demographic covariates, and the type of post-secondary institution in which students first enrolled following graduation from high school. A Sankey diagram corresponding to this model and illustrating the proportions of students achieving post-secondary outcomes just listed after enrolling in different types of post-secondary institutions is included in Figure 5. Flows from post-secondary institution type to post-secondary outcome are colored according student enrollment in various STEM course-taking patterns and enrollment in charter or non-charter schools. Results from this model are provided in Table 4 with coefficients of the predictor variables of interest (charter school, STEM course-taking patterns, and their interaction) exponentiated and visualized in Figure 6, giving the relative change in odds associated with these predictor variables.

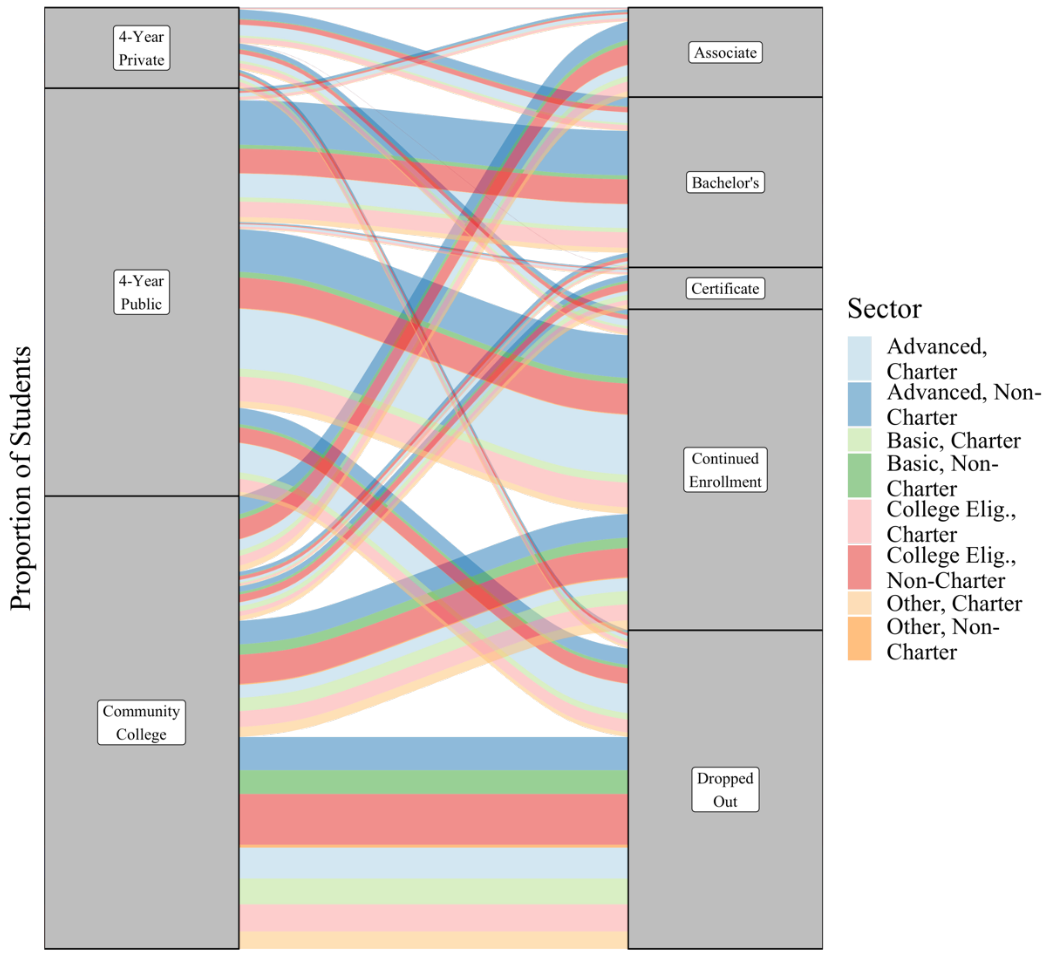

Figure 5. Sankey diagram showing the proportions of students from different types of post-secondary institutions achieving post-secondary outcomes. Color represents sector and secondary STEM course-taking.

Results from the multinomial logistic regression model detailed in Table 4 and Figure 6 indicate that attending a charter schools (as compared to attending a non-charter school) is not associated with any statistically significant difference in the likelihood of a student earning a post-secondary degree or certificate or continuing to be enrolled in an institute of higher education relative to dropping out. Enrolling in an advanced STEM curriculum at the secondary level is associated with increased likelihoods of earning associate and bachelor's degrees and of continued enrollment in a post-secondary institution 4 years following graduation from high school. Compared to secondary enrollment in a college preparatory STEM course set, enrollment in basic or other STEM course sets are associated with decreased probabilities of earning a degree or continued enrollment as relative to dropping out, and enrollment in basic STEM course sets is associated with a decreased probability of earning a post-secondary certificate.

Table 4. Results from multinomial logistic regression predicting the likelihood of students achieving different post-secondary outcomes within 4-years of their graduation from high school.

	Certificate			**Associate**			**Bachelor's**			**Still Enrolled**		
Coefficients	**Est**	**SE**	**Sig**	**Est**	**SE**	**Sig**	**Est**	**SE**	**Sig**	**Est**	**SE**	**Sig**
Intercept	-2.09	0.05	***	-1.29	0.03	***	-2.58	0.05	***	-1.49	0.03	***
Charter	-0.32	0.32		0.12	0.18		-0.36	0.32		0.04	0.17	
Adv. Courses	0.08	0.05	.	0.28	0.03	***	0.37	0.04	***	0.17	0.03	***
Basic Courses	-0.32	0.06	***	-0.64	0.04	***	-0.85	0.07	***	-0.5	0.04	***
Other Courses	-0.38	0.23	.	-1.27	0.15	***	-1.02	0.22	***	-0.86	0.13	***
Charter, Adv.	0.17	0.40		-0.48	0.25	.	-0.40	0.42		0.07	0.21	
Charter, Basic	0.32	0.50		0.14	0.29		0.65	0.52		0.26	0.27	
Charter, Other	-0.13	1.22		0.25	0.42		1.75	0.54	**	-0.35	0.46	
Asian	0.47	0.11	***	0.57	0.07	***	0.61	0.09	***	0.94	0.06	***
Black	-0.78	0.08	***	-0.48	0.05	***	-0.9	0.07	***	0.07	0.04	.
Latinx	-0.04	0.05		0.07	0.03	*	-0.35	0.04	***	0.06	0.03	.
Female	-0.06	0.04		0.44	0.02	***	1.03	0.04	***	0.19	0.02	***
Econ. Dis.	-0.36	0.05	***	-0.48	0.03	***	-1.11	0.05	***	-0.76	0.03	***
Gifted	0.08	0.07		0.37	0.04	***	0.81	0.05	***	0.1	0.04	*
LEP	0.31	0.13	*	-0.21	0.10	*	-0.69	0.24	**	-0.31	0.12	**
SPED	0.14	0.07	.	-0.73	0.06	***	-1.76	0.19	***	-0.79	0.07	***
Private 4-Yr	-0.84	0.13	***	-0.79	0.07	***	1.02	0.06	***	1.21	0.04	***
Public 4-Yr	-0.82	0.05	***	-1.49	0.04	***	0.39	0.04	***	0.38	0.03	***

*** p < 0.01; ** p < 0.01, * p < 0.05, . p < 0.10

The interaction between charter school attendance and enrollment in an advanced STEM course set are associated with decreased likelihoods of earning post-secondary degrees; however, these coefficients are not statistically significant. A statistically significant positive coefficient for the interaction between charter school attendance and enrollment in an "other" course set is associated with increased likelihood of earning a bachelor's degree. Thus, post-secondary outcomes for students enrolled in "other" course sets in charter schools are statistically different from the post-secondary outcomes for students in non-charter schools who enroll in "other" course sets.

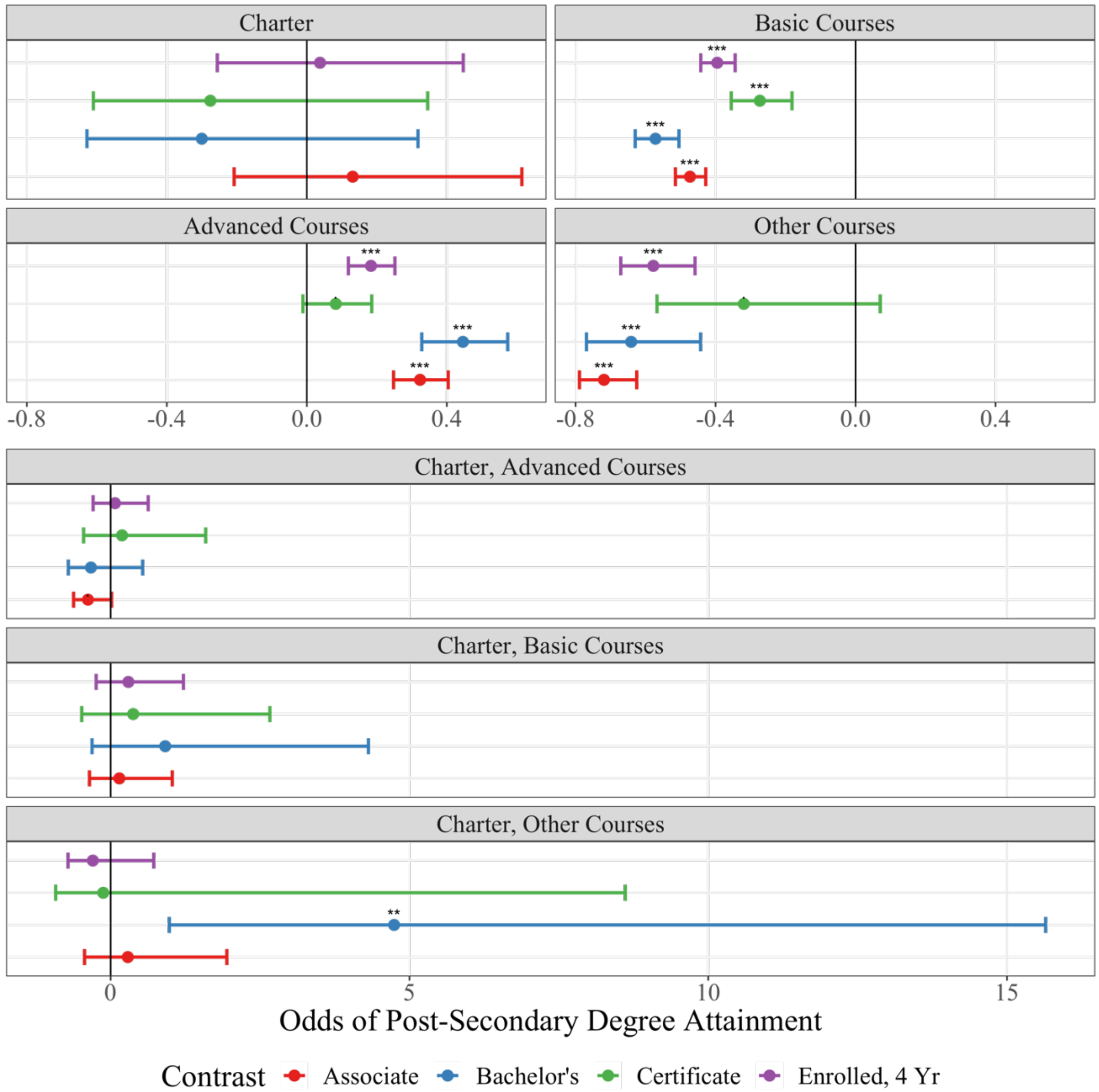

Figure 6. Change in odds of earning various post-secondary degrees associated with charter school enrollment, enrollment in different sets of secondary STEM courses and the interaction between the two.

The final multinomial logistic regression predicts the likelihood of earning different kinds of STEM degrees within four years of graduating high school. The coefficients from this model are provided in Table 5. As with the coefficients from the other models constructed, exponentiating the values in Table 5 gives the change in the odds of a student earning the indicated type of STEM degree relative to not earning any degree. The exponentiated coefficients for charter schools and secondary STEM course-taking are plotted in Figure 7.

Table 5. Multinomial regression output giving the probability of earning different types of post-secondary degrees in STEM disciplines relative to not earning any degree.

	Non STEM Degree			**STEM Certificate**			**STEM Associate Degree**			**STEM Bachelor's Degree**		
Coefficients	**Est**	**SE**	**Sig**	**Est**	**SE**	**Sig**	**Est**	**SE**	**Sig**	**Est**	**SE**	**Sig**
Intercept	-0.90	0.03	***	-4.61	0.13	***	-3.09	0.08	***	-4.78	0.11	***
Charter	-0.10	0.16		0.28	0.58		-0.87	0.74		-0.50	0.77	
Adv. Courses	0.27	0.03	***	-0.04	0.11		0.24	0.07	**	0.53	0.09	***
Basic Courses	-0.58	0.04	***	-0.37	0.15	*	-0.81	0.11	***	-0.77	0.18	***
Other Courses	-0.77	0.10		-0.88	0.65		-4.14	1.63	*	-1.23	1.14	
Charter, Adv.	-0.26	0.22		-1.74	1.17		-0.33	1.02		-0.41	0.97	
Charter, Basic	0.30	0.25	***	-0.05	0.96		-6.17	25.1		1.33	1.13	
Charter, Other	0.72	0.30		-5.42	28.6		4.26	2.04	*	-1.38	8.29	
Asian	0.50	0.06		-0.41	0.43		0.31	0.20		1.48	0.14	***
Black	-0.65	0.04		-0.74	0.19	***	-0.78	0.13	***	-0.52	0.15	***
Latinx	-0.03	0.03	**	0.03	0.12		-0.01	0.07		-0.22	0.09	*
Female	0.54	0.02	***	0.27	0.09	**	-0.29	0.06	***	0.92	0.08	***
Econ. Dis.	-0.59	0.03	***	-0.17	0.12		-0.58	0.07	***	-1.03	0.10	***
Gifted	0.43	0.03		0.33	0.15	*	0.49	0.09	***	1.13	0.09	***
LEP	-0.05	0.08	***	0.36	0.28		0.15	0.25		-0.41	0.48	
SPED	-0.48	0.05	***	-0.05	0.19		-0.86	0.18	***	-1.47	0.42	***
Private 4-Yr	-0.15	0.05	***	-0.42	0.27		-0.70	0.18	***	1.18	0.13	***
Public 4-Yr	-0.76	0.03		-0.40	0.12	***	-0.91	0.08	***	0.72	0.08	***

*** $p < 0.01$; ** $p < 0.01$, * $p < 0.05$, . $p < 0.10$

Although enrolling in a charter school is associated with statistically significant increases in the probability that a student enrolls in a private or public 4-year university or an out-of-state post-secondary institution, charter schools are not associated with any statistically significant differences in the likelihood of a student earning a STEM degree within 4-years of graduating from high school. In addition, this effect is not mediated by course-taking in STEM.

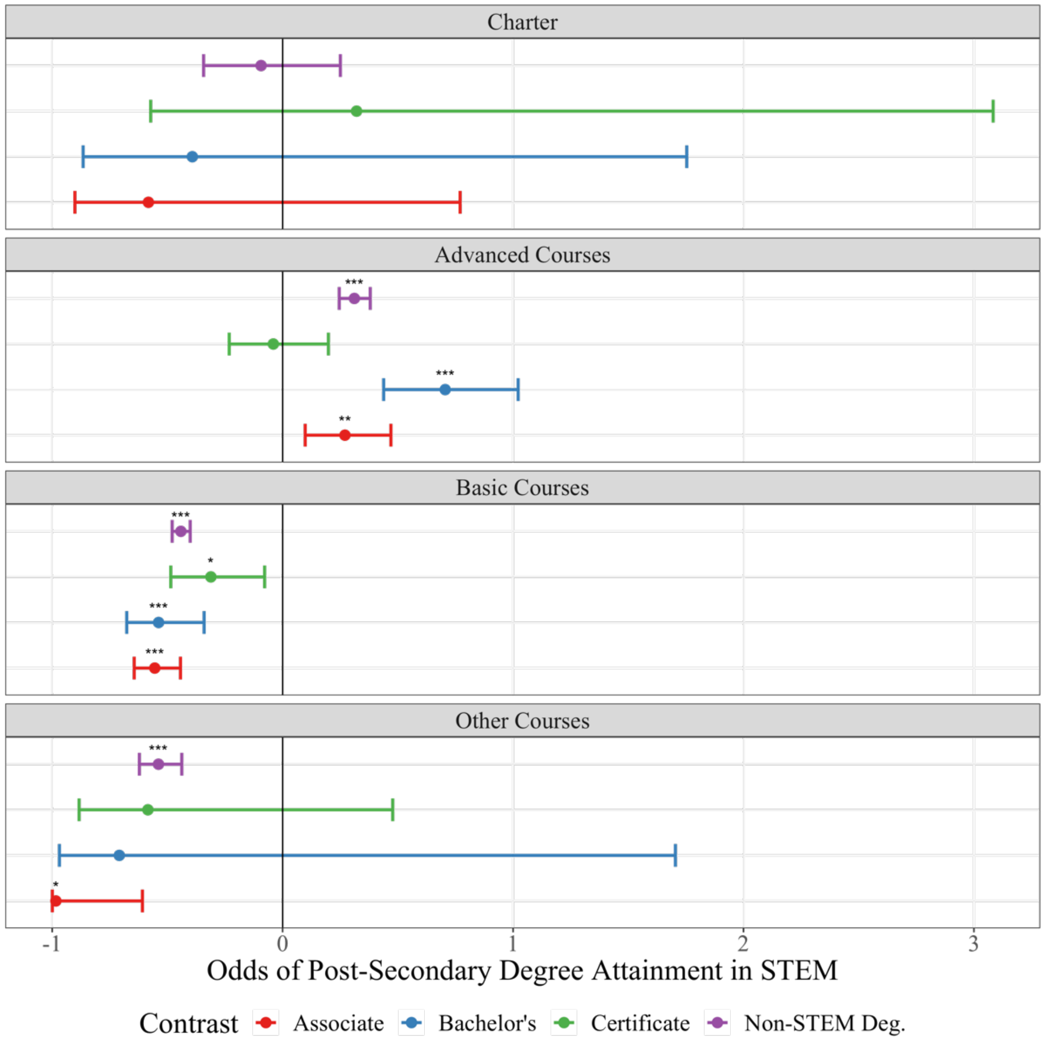

Figure 7. Change in odds of earning various types of post-secondary STEM degrees associated with charter enrollment and in secondary STEM course taking.

Individually, enrolling in an advanced STEM course set is associated with an increased likelihood that a student earns a non-STEM, STEM associate, or STEM bachelor's degree relative to no degree at all. Enrolling in a basic high school set of STEM courses, by contrast, is associated with a decreased probability that a student earns a non-

STEM degree, STEM certificate (such as a certificate in information technology), STEM associate degree, or STEM bachelor's degree relative to earning no degree at all. That charter schools are associated with increased college enrollment, but not differences in post-secondary outcomes other than enrollment (e.g., degree attainment) is consistent with literature elsewhere. Possible reasons for this and implications are explored in the discussion.

DISCUSSION

Consistent with extant literature and achievements celebrated on charter school websites (e.g., KIPP and IDEA), charter school attendance was associated with increased odds of a student attending a post-secondary institution following their graduation from high school. In addition, students' secondary STEM course-taking patterns are related to the likelihood of pursuing post-secondary education the year following high school graduation. Relative to a set of STEM courses categorized as college preparatory, in which students take core STEM courses in addition to additional elective or advanced courses, students who enroll in more advanced STEM elective courses are more likely to pursue higher education and students enrolling in basic sets of STEM courses at the secondary level or students in course sets characterized by high mobility or coursework tailored for students eligible for special education services are less likely to pursue post-secondary education.

These findings are not altogether surprising. Many charter schools—particularly "no excuses" charters—imbue the virtues of higher education upon their students and have a college preparatory focus. Moreover, that charter schools advertise high college admissions figures may indicate that charter schools support students' post-secondary pursuits differently than non-charter schools, as this affords them a competitive edge in recruiting students. This is an area that warrants additional qualitative research. In addition, it is reasonable that students taking more rigorous coursework at the secondary level are more likely to pursue post-secondary education. The rigor of secondary academic coursework is one metric by which students are granted admissions to post-secondary institutions, and "Advanced Placement" courses are designed specifically as means by which high school students can earn college credits.

It is of concern, however, that the advantage charter school attendees experience in terms of post-secondary enrollment does not extend to other, and arguably more important, post-secondary outcomes as indicated in results from the second logistic regression model detailed in Table 2. There is no statistically significant difference in the probability of earning a post-secondary degree or certificate within four years of graduating from high school between students who attended a charter school and those who attended a non-charter public school. Of note, a statistically significant interaction between attending a charter schools and enrolling in an advanced set of STEM courses is associated with a decreased likelihood of earning a post-secondary degree or certification within 4 years of graduating from high school relative to the likelihood of dropping out of post-secondary education. Thus, students in non-charter public schools enrolling in advanced sets of secondary STEM courses are more successful at the post-secondary level than students enrolling in comparable sets of courses in charter schools. Together, these findings suggest that charter schools may be able to improve the likelihood of enrolling in post-secondary education, but they may not be equipping students with the skills they need to succeed at the post-secondary level, particularly among students taking advanced STEM courses, providing some evidence to support the hypothesis offered by Dobbie and Fryer (2016).

Multinomial regression models make it possible to explore how charter school attendance and secondary STEM course enrollment affect post-secondary enrollment and outcomes with greater nuance. Rather than explore the probability of pursuing post-secondary education or earning a post-secondary degree or certificate, multinomial regression models made it possible to explore the probability of enrolling in different kinds of post-secondary institutions and of earning different kinds of post-secondary degrees.

Consistent with results from the first logistic regression model (Table 1), output from the multinomial regression model predicting the likelihood of students enrolling in different types of post-secondary institutions (Table 3) indicates that charter schools are associated with increases in the likelihood of students enrolling in 4-year universities (public, private, and out-of-state). The interaction between charter school attendance and enrollment in advanced STEM courses at the secondary level is associated with an additional increase in the probability of enrolling in an out-of-state post-secondary institution, and the interaction between charter school attendance and enrollment in a basic set of STEM courses is associated with an increased probability of enrolling in a public 4-year university.

The multinomial regression model giving the probability of students earning different kinds of post-secondary degrees (Table 4) reveals that there is no statistically significant difference in post-secondary outcomes between students attending charter schools and students attending non-charter public schools. As results from other models indicate, STEM course-taking patterns are better predictors of the post-secondary degree attainment. Compared to students enrolled in college preparatory STEM courses, those enrolled in advanced secondary STEM courses are more likely to earn associate degrees, bachelor's degrees, or to continue to be enrolled than they are to have dropped out 4 years after graduating from high schools. The statistically significant interaction between charter school attendance and enrollment in a set of STEM courses designated as "other" indicates that enrolling in this set of courses in charter schools is associated with increased likelihood of earning a bachelor's degree.

Secondary course pathways associated with mobility are grouped in this category, and charter school students are more likely than non-charter public school students of being mobile. It is reasonable that charter school students are more mobile than non-charter school students, as to enroll in a charter school requires families to submit applications to these schools and leave the non-charter public school to which a student would have attended. Moreover, arguments for increasing school choice posit that families dissatisfied with a given school can simply move elsewhere, so enrollment in a charter school could plausibly indicate that these students' families are more amenable to moving between schools to search for academic environments they perceive as superior. If concern over the academic quality in a given school is what drives mobile students to both transfer into and out of charter schools, then such concern over academic quality—either on the part of individual students or their families—may also explain why these students also are more likely to earn bachelor's degrees than mobile peers in non-charter public schools.

Although a statistically significant interaction between charter school attendance and enrollment in an advanced set of secondary STEM courses was statistically significant in the logistic regression model predicting the likelihood of post-secondary degree attainment, this interaction is not statistically significant in the multinomial regression model predicting the likelihood of earning certain kinds of post-secondary degrees. Nevertheless, this interaction is negative in magnitude for contrasts predicting the probability of earning an associate or bachelor's degree relative to the probability of dropping out of post-secondary education. Thus, the decreased likelihood charter school attendees who had enrolled in advanced sets of STEM courses is driven primarily by students not earning these two degrees.

With respect to post-secondary attainment in STEM disciplines, charter schools are not associated with any statistically significant change in the likelihood of earning a post-secondary degree or certificate in STEM disciplines. Significant interactions between charter school attendance and enrollment in either basic sets of STEM courses or “other” sets of STEM courses are significant predictors of the likelihood of earning a non-STEM bachelor’s degree and of earning an associate degree in a STEM discipline. That students enrolling in basic sets of STEM courses at the secondary level in charter schools have a higher probability of earning a non-STEM post-secondary degree or certificate as compared to peers taking similar STEM courses in non-charter schools suggests academic programming in some charter schools may equip students for post-secondary success better than non-charter public schools; however, it would be instructive for future research to investigate what kinds of post-secondary degrees and certificates are driving this interaction. That charter school students enrolling in “other” sets of STEM courses have higher probabilities of earning a STEM associate degree is likely an artifact of the types of “other” courses identified in charter and non-charter schools. As posited earlier, charter school students are more likely to be associated with mobility, which may signify that these students are concerned with school quality to a greater degree than mobile students in non-charter schools. By contrast, non-charter public school students are more likely to enroll in sets of STEM courses tailored for SPED students, and SPED designation is associated with decreased probabilities of post-secondary enrollment and degree attainment. Since both “mobility” and “SPED” course patterns are grouped in the “other” category, sector differences for students enrolled in “other” sets of STEM courses likely reflects that charter and non-charter public schools serve different populations of students instead of suggesting that charter schools offer better academic programming in “other” STEM courses.

Chapter 3: Teaching in a Parallel Universe: Assignment of Alternatively and Traditionally Certified STEM Teachers to Courses in Charter and Non-charter Public Schools

INTRODUCTION

Charter schools and alternative teacher certification programs are concurrent education reforms in the United States that have grown substantially since their inception. Typically, charter schools operate independently of the local districts in which they are situated and are therefore not subjected to many of the same regulations as non-charter district schools. Charter school proponents argue that this independence from local school districts frees charter schools from stifling bureaucracy and affords them opportunities to more flexibly and effectively meet the needs of students and families (Bierlein & Mulholland, 1994; Budde, 1988; Friedman, 2002). In a similar vein, alternative teacher certification pathways exist outside of traditional, university-based teacher preparation programs (TPPs) and are positioned by proponents as institutions that are equipped to recruit and train high-quality teachers with greater efficacy. Critics of traditional TPPs have leveraged concerns over the quality and quantity of teachers prepared in these programs, and alternative TPPs emerged in response to these concerns by reducing barriers to entering the teaching profession and by providing accelerated pathways to certification (Adelman et al., 1986; Ludlow, 2013; Suell & Piotrowski, 2007).

Charter schools and alternative pathways to teacher certification are both market-based reforms in which deregulation and competition are introduced to spur innovation and increase efficiency within public education structures that have been widely cast in political and public circles as inadequate and resistant to change (C. Clark, 2000; Guggenheim, 2010; Labaree, 1996; National Commission on Excellence in Education, 1983; Shokraii, 1996). Recently, both charter schools and alternative teacher preparation pathways have benefitted from political support as federal initiatives have provided financial incentives for states to expand deregulation within their public education systems. The motivations for these federal incentives include increasing teacher recruitment—particularly in hard to staff content areas such as the STEM (science, technology, engineering and mathematics) disciplines—and encouraging educational innovation to improve outcomes among socioeconomically disadvantaged students who have historically performed more poorly than their advantaged peers (U.S. Department of Education, 2009). In addition to benefitting from federal incentives, both charter schools and alternative teacher preparation programs have received positive media attention, such as in 2010's *Waiting for Superman*, which chronicled the ways by which inefficiency and stagnation within the public education system resulted in subpar outcomes, particularly for students from socioeconomically disadvantaged backgrounds (Guggenheim, 2010).

Although charter schools and alternative teacher preparation are reforms that were initiated independently, they have many ideological commonalities, and scholars have identified and theorized the interconnections between them (Kretchmar, 2014; Mungal, 2016; Stitzlein & West, 2014). For example, Mungal (2016) describes an emerging education structure—consisting of alternative teacher certification, charter schools, and graduate degree programs tailored specifically for charter school teachers—that parallels the traditional education structure in which teachers are prepared in university-based certification programs and subsequently employed by non-charter public schools. Stitzlein and West (2014) chronicle the ideological similarities between alternative graduate degree programs and charter schools, noting that many charter school organizers have structured new graduate programs of education to align with values espoused by and pedagogies employed in "no-excuses" charter schools (in which students attend schools for longer days, are held accountable to strict behavioral expectations, and engage in rigorous preparation for standardized assessments).

Given the growing prevalence of charter schools nationwide, scholars have begun to pursue research investigating how teachers perceive and navigate educational labor markets in which varying levels of charter schools are present (Cannata, 2011; Carruthers, 2012; Gulosino et al., 2019; Jabbar et al., 2019). Results from these studies suggest that teachers' sector preferences are motivated by a range of factors, including ideological match, job security, school location, and teachers' age and experience. A subset of the researchers investigating how teachers navigate the educational labor market have considered teachers' certification pathways in their analyses (Lefebvre & Thomas, 2017; Maloney & McKenzie-Thompson, 2013). These results show that a higher percentage of alternatively certified teachers work in charter schools than in non-charter public schools and suggest that this difference may be attributable to the close relationships between alternative certification programs and charter schools.

A separate realm of research has explored the factors influencing teacher mobility between and assignment within schools (Chingos & West, 2011; Donaldson & Johnson, 2010; Feng, 2010; Loeb et al., 2012); however, most of this research has neither attended to teachers' preparation pathway nor considered school sector. Scholars researching charter schools have highlighted the importance of investigating the internal conditions within charter and non-charter public schools that may be responsible for sector differences in student outcomes (Berends & Donaldson, 2016; Cannata & Penaloza, 2012; Preston et al., 2012). Given the connections between charter schools and alternative certification pathways, the effects of teacher preparation pathway within school sector are necessarily important to consider when exploring the internal conditions within schools that may be responsible for differential student outcomes. As such, it is critical to evaluate the factors influencing teachers in charter and non-charter public schools as an additional way to assess the degree to which the convergence of alternative preparation pathways and charter schools either has or has not led to the innovation and efficiency anticipated by education reformers.

The primary goal of this study is to identify factors that influence teacher assignment and to explore the ways in which teacher assignment is mediated by teachers' preparation pathway, school sector, and the interaction between the two. Specifically, this paper addresses the following research questions:

1. What factors influence how secondary teachers are assigned to teach STEM courses?
2. Do the factors influencing secondary teacher course assignment in schools vary by sector?
3. Are factors influencing secondary teacher course assignment different for teachers certified in alternative and traditional preparation programs?
4. Are any teacher preparation pathway differences in course-assignment mediated by school sector?

To explore these research questions, this study analyzes statewide data available in Texas at the student- and teacher- levels by building logistic and multinomial logistic models to predict the likelihood of alternative and traditionally certified teachers being assigned to different kinds of STEM courses in secondary charter and non-charter public schools. There are two primary motivations for the focus on STEM disciplines. First, students' preparation in STEM disciplines (or the perceived lack thereof) is an oft cited concern within influential governmental reports that have been used widely to criticize the public education system, thereby bolstering support for market-based educational reforms (Goals 2000, 1994; National Commission on Excellence in Education, 1983; U.S.

Department of Education, 2009). Thus, it is of interest to policymakers and researchers to ascertain the degree to which the proliferation of charter schools and alternative teacher certification have independently and jointly affected students' preparation in STEM disciplines. In other words, both charter schools and alternative teacher certification are celebrated as reforms to improve upon the shortcomings of a "failing" education system; are these reforms making any appreciable differences in preparing students to participate in disciplines often portrayed as critically important to the economic and technological well-being of the United States?

The second motivation for focusing on the STEM disciplines is because both charter schools and alternative teacher certification are reforms aimed at serving socioeconomically disadvantaged students belonging predominately to historically marginalized ethnic groups (Gulosino & dEntremont, 2011; Logan & Burdick-Will, 2016; Ludlow, 2013). This demographic of students is also underrepresented in STEM disciplines—particularly the physical sciences—at the secondary and post-secondary levels (National Center for Education Statistics, 2019). Given that charter schools and alternative teacher certification target socioeconomically disadvantaged who are underrepresented in the STEM disciplines, it is a matter of equity to investigate the degree to which the growing influence of market-based reforms serves either to dismantle or uphold the structures that have precluded equitable participation in STEM. Investigating the factors influencing teacher assignment in charter and non-charter public schools is a step toward that goal.

Finally, in developing the research focus of this study, it is important to acknowledge the broad federal mandate of high-stakes accountability within which public education systems currently operate. Both charter schools and non-charter public schools are held accountable for student achievement as assessed through standardized exams.

Since high-stakes accountability measures are used so ubiquitously to evaluate institutions of public education, it is important to consider how these pressures influence teachers' assignment to courses in charter and non-charter public schools, with particular attention to sector differences in schools' responses to these pressures. To investigate this question, logistic and multinomial logistic models that account for teachers' value-added scores in tested STEM subjects are constructed in order to assess teachers' probability of continuing to be assigned to the same STEM subject in a subsequent year and to identify prominent assignment pathways into and out of tested STEM subjects in charter and non-charter schools.

LITERATURE REVIEW

The literature review highlights two threads of research that I aim to bridge in this study. The first line of research investigates factors impacting teacher dynamics, focusing particularly upon the ways in which teachers are hired and assigned to courses in their schools and upon the effects that lead to teacher turnover. Many of these studies have focused on elementary and middle schools with little attention given to teacher dynamics in secondary schools. In addition, this research has not explored whether or not there are sector differences in how teachers are assigned to classes, nor has this research attended to teachers' preparation pathways.

The second thread of research investigates how teachers navigate labor markets in which charter schools and non-charter public schools are both present. Some of these studies consider teacher preparation pathway and explore the ideological similarities between charter schools and alternative certification pathways. The bulk of this research does not, however, explore how teachers are assigned to courses. Thus, I make the case through this literature review that there is a need for research to investigate the factors influencing teacher assignment and mobility in charter and non-charter schools with particular attention given to the effects of teacher preparation pathway in each sector. Moreover, given the large focus on teachers in elementary and middle schools in the extant research literature, there is also a need for researchers to focus upon teachers at the secondary level.

Factors Impacting Teacher Hiring, Assignment, and Mobility

One line of research investigating how teachers are assigned to teach courses has focused on the ways by which teachers are matched to students. This research suggests that teachers with higher qualifications are more likely to be matched with high-performing students. Donaldson (2013) reports both that teacher assignment in schools is often dominated by seniority and that senior teachers elect to teach classes consisting of high-performing students. Player (2010) corroborates this finding, providing evidence suggesting that favorable assignment for highly qualified and more experienced teachers is one way in which principals compensate teachers who do well in their schools.

In a quantitative study analyzing data from fifth grade classrooms in North Carolina, Clotfelter, Ladd, and Vigdor (2006) find that teacher sorting occurs both within and between schools. Teachers with greater experience and from more prestigious universities are more likely to teach at schools serving primarily advantaged student populations while their less experienced colleagues are more likely to serve in socioeconomically disadvantaged schools serving high proportions of students from ethnic minority populations. Within schools, teachers with low licensure exam scores are assigned to classes consisting of fewer white students, fewer students whose parents went to college, and students who historically had performed poorly on standardized exams, whereas Nationally Certified Board teachers are more often assigned to classes with higher performing students. Notably, these patterns in teacher assignment are problematic because disadvantaged students are disproportionately taught by underprepared, underperforming novice teachers who are more likely to leave the profession (Donaldson & Johnson, 2010; Feng, 2010).

There is evidence to suggest that mobility patterns of teachers may exacerbate these inequities. In New York City, although first year teachers who were ineffective at improving student outcomes on standardized exams had high rates of attrition among both schools with high achieving student populations and schools with low achieving student populations, second and third year teachers with demonstrated abilities to improve student test scores were more likely to move to schools with higher student achievement while ineffective teachers tended to stay in schools with lower student achievement (Boyd et al., 2008).

Steele et al. (2015) also document differences between teachers serving socioeconomically disadvantaged students and those serving more advantaged students. They find that teachers serving disadvantaged students are less experienced, have lower college GPA's, and graduate from less prestigious institutions of higher education. Moreover, these authors explore the factors that influence teacher sorting by using teachers' value-added scores to predict the likelihood of teacher turnover in elementary and middle schools. Value-added scores for teachers are computed through statistical models in which students' scores on standardized exams are regressed on their test scores from the prior year in that subject. From these models, coefficients for individual teachers are computed, and these "value-added" coefficients are used to represent teachers' demonstrated ability to either increase or decrease student achievement on standardized exams.

In their study, Steele et al. (2015) find that teachers with low value-added scores are more likely to work in schools with higher concentrations of students from underrepresented ethnic minority groups, which is consistent with their finding that these teachers are less qualified than teachers in more privileged settings. Despite differences in teachers' qualifications and teachers' average value-added scores between schools serving high and low privilege student populations, Steele et al. (2015) do not find evidence that the mobility dynamics differ between these schools. The likelihood of teacher turnover in schools with high concentrations of ethnic minority students is not mediated by teachers' value-added score.

Given the ubiquity of standardized exams in the current educational era, teachers' value-added scores have been used in an array of studies examining the dynamics impacting teacher assignment and mobility in public schools. Analyzing data on elementary school teachers in North Carolina, Ost and Schiman (2015) use teachers' value-added scores to predict the likelihood that elementary school teachers are reassigned to teach different grades in subsequent years. Although they find some evidence that a lower value-added score corresponds to an increased likelihood that a teacher is reassigned to a different grade in a subsequent year, this effect is not statistically significant in all of their models. Rather than individual teacher characteristics driving teacher reassignment, school-level characteristics seem to be more influential drivers of teacher reassignment (Ost & Schiman, 2015). In addition, teachers who are reassigned to teach different grade levels are more likely to leave their schools. Thus, it is important that research continue to investigate what factors lead to teachers' reassignment and to evaluate whether reassignment leads to turnover in additional contexts.

Chingos and West (2011) compute value-added scores for teachers teaching high-stakes courses (in all subjects), defined as courses in which students are assessed on standardized exams that are used to rate schools. Using the value-added scores they compute as independent variables, these authors build models predicting the likelihood of teachers transitioning out of high-stakes classrooms. Their results suggest that teachers with high value-added scores are more likely to become principals, assistant principals, and instructional leaders, whereas teachers with low value-added scores are more likely to be moved from high-stakes classrooms to low-stakes classrooms. The evidence Chingos and West provide exemplifies some of the ways in which the prevalence of high-stakes standardized exams directly impacts teachers' assignment.

Many studies using teachers' value-added scores to explore hiring, assignment, and mobility of public school teachers draw mainly upon data from elementary and middle school students (Boyd et al., 2006, 2008; Chingos & West, 2011; Hanushek et al., 2016; Hanushek & Rivkin, 2010; Loeb et al., 2012; Ost & Schiman, 2015; Steele et al., 2015). This is due to the fact that individual schools' adequate yearly progress, as mandated by No Child Left Behind, is determined in large part by students' performance on standardized exams in grades 3 through 8. The readily available data for these grades make it easy to compute value-added scores for elementary and middle school teachers. In high school grades, however, standardized assessments are not taken with the same regularity, meaning the factors influencing teacher assignment, hiring, and mobility in secondary schools have not received the same amount of attention in the research literature. In addition, standardized exams in science are not offered with the same frequency that English language arts (ELA) and mathematics exams are, thereby making it difficult for researchers to evaluate science teachers in the same manner as ELA and mathematics teachers. In their study on the effects of value-added on teachers' course assignments, Steele et al. (2015) report that relative to ELA and mathematics teachers, there are larger disparities in the value-added scores of science and social studies teachers between schools serving high and low concentrations of underrepresented ethnic minority students, suggesting that pressure from high-stakes accountabilities affects teacher assignment more in some subjects (ELA and mathematics) than in others (science and social students).

There is evidence indicating that factors affecting teacher assignment practices at the middle and high-school levels are also at play at the secondary level. In a prior study evaluating the efficacy of alternatively and traditionally certified secondary STEM teachers upon student learning in algebra I and biology, I, along with coauthors, found that a teacher's value-added score was statistically significantly related to the probability of that teacher continuing to teach the same tested-STEM subject in the subsequent year (Marder et al., 2020). In this study, estimates of the effects of teacher preparation pathway upon student achievement gains in math and science became less significant over time, likely a result of effective teachers continuing to teach tested STEM subjects with less effective teachers moving away from these subjects. As my coauthors and I argue, this yields both practical and methodological concerns (David & Marder, 2018). That teachers are seemingly being assigned to classes and subjects such to maximize student achievement on standardized exams necessitates researchers investigate what other factors influence the likelihood of teachers being assigned to or reassigned from high-stakes STEM subjects. In addition, it is important to consider how these factors affect how teachers are assigned to classes more generally, not just in the subjects that are predominately used to hold schools accountable for adequate yearly progress.

In addition to the practical considerations of teacher matching, these assignment practices also yield methodological concerns for researchers seeking to evaluate teacher efficacy using value-added modeling. Dieterle, Guarino, Reckase, and Wooldridge (2015) present evidence to suggest that schools often group students according to prior performance and non-randomly assign teachers to these classes, effects to which value-added modeling is sensitive. Clotfelter et al. (2006) also report that biases due to teacher and student matching exacerbate correlations between teacher qualifications and student outcomes. That our estimates gradually decreased in magnitude and significance over time is evidence of the effects of teacher assignment practices upon value-added modeling (Marder et al., 2020). Better understanding the dynamics influencing teacher assignment is not only important for researchers and policy makers to evaluate the degree to which students have equitable access to high quality teachers, but it is also important in order to consider how these dynamics affect researchers' capacities to reliably evaluate educational systems using observational data.

How Teachers Navigate the Educational Labor Market in an Era of School Choice

Recent research investigating how the growth of charter schools has influenced the ways in which teachers navigate the educational job market have leveraged principles from segmented labor market theory (Cannata, 2011; Gulosino et al., 2019; Jabbar et al., 2019). As opposed to workers in a unified labor market, in which workers are able access to all professional options, workers in a segmented labor market are limited to a subset of the entire labor market because informal and institutional barriers limit their mobility between divisions in the market. Within a segmented labor market, one subset of the market—the primary market—has more favorable characteristics than the other—the secondary market. For example, the primary market is associated with higher wages and job security, whereas the secondary labor market is characterized by lower wages and less stability. These distinctions align with characteristics of the educational labor market in which charter schools and non-charter schools are both present. In these markets, teachers in non-charter public schools typically have higher salaries and greater job stability, as opposed to charter school teachers who are hired at-will and typically receive lower salaries. Therefore, literature drawing from segmented labor market theory to analyze the educational job markets with charter schools argues that professional options in the non-charter sector constitute a primary market and professional options in the charter sector comprise the secondary labor market.

Drawing upon both qualitative and quantitative data from prospective elementary school teachers in Michigan, Cannata (2011) reports that the introduction of charter schools to the educational labor market has resulted in the segmentation predicted by the segmented labor market theory. Results indicated that prospective elementary school teachers tended to prefer non-charter public schools in their job search because of unfamiliarity with the charter school sector, the perceived ambiguity of the institutional status of charter schools within the public education system, and a general desire for features of the primary segment (e.g., higher wages and greater job security). Statistical models from this study provided evidence that prospective elementary teachers were more likely to apply to charter schools if they also applied to work at a private school, desired to work in an urban school, attended a teacher preparation program that had authorized a charter school, or lived in areas with charter schools present.

In another study, Gulosino et al. (2019) also find evidence that the introduction of charter schools has resulted in segmentation of the labor market. Their models show that newly hired teachers in secondary charter schools have higher rates of turnover than newly hired teachers in non-charter public schools and that newly hired charter school teachers at both elementary and secondary schools are more likely to leave teaching than non-charter public school teachers. Gulosino et al. (2019) argue that these pervasive differences between charter school teachers' and non-charter school teachers' rates of turnover and propensities to leave the profession result from the differing organizational structure of charter and non-charter public schools. Moreover, that these two markets have distinct characteristics (e.g., charter schools have notably less stability than non-charter schools) is consistent with the primary and secondary characteristics of subdivisions within a segmented labor market. With respect to teacher preparation pathway, teachers from traditional and alternative preparation programs had a similar likelihood of turnover in non-charter public schools; however, traditionally prepared teachers working in charter schools were more likely to be retained.

In an analysis of interview data from prospective and transitioning teachers (e.g., teachers new to the profession and experienced teachers searching for new positions), Jabbar et al. (2019) similarly draw from segmented labor market theory to explore how teachers navigate various educational labor markets in which there are varying concentrations of charter schools. As opposed to prior work using segmented labor market theory, these authors focused upon qualitative data to gain deeper insight into the personal and institutional factors that influenced teachers' decisions to pursue jobs in the primary and secondary markets. In general, teachers preferred non-charter schools over charter schools due to the greater job security and higher wages. However, some teachers preferentially sought employment in charter schools because these schools aligned with their personal ideological beliefs. The authors argue that these personal preferences, in addition to structural policies, served as barriers that contribute to the segmentation of the educational labor market.

The relationship between the alignment of teachers' personal ideological beliefs with charter school missions and teachers' individual preferences for working in charter schools is also noted elsewhere. Cannata and Penaloza (2012) characterize differences between teachers working in charter and non-charter schools, noting that teachers' agreement with the mission of the school, increased autonomy over their instruction, and influence over school policies, among other factors, are possible reasons why teachers decided to work in charter schools. Additionally, teachers working in non-charter public schools more often chose those schools for job security, the positive reputation of the school, and the proximity of the school to where they lived.

Given the influence of ideological match upon teachers' preferences for employment in segmented labor markets, it is important for researchers to consider what role alternative teacher certification programs play in the segmentation of the educational labor market. A number of scholars have described how market-based educational reforms—namely alternative teacher certification and charter schools—are aligned in their neoliberal ideologies (Kretchmar, 2014; Kretchmar et al., 2014; Lefebvre & Thomas, 2017; Maloney & McKenzie-Thompson, 2013). Teach For America (TFA), which recruits high-achieving college graduates, places them in alternative certification programs, and matches TFA corps members with high-needs schools, has many inroads with the charter school movement (Kretchmar, 2014; Kretchmar et al., 2014). In addition to sponsoring policies that support the expansion of charter schools, TFA also instills in its corps members values that are aligned with those of many charter schools. For example, Kretchmar (2014) argues that TFA profoundly shapes its corps members' beliefs about education in such a way that they believe the charter school autonomy allows for better professional opportunities that will ultimately translate to improved student outcomes.

Maloney and McKenzie-Thompson (2013) note that, despite wanting qualitatively similar things from their teacher certification programs, teachers in charter and non-charter public schools have drastically different ideas about conditions in the opposite sector. For example, charter school teachers perceived they received greater support from their schools, were not stifled by union regulations, and were able to work in an environment that prioritized achievement to a greater degree than teachers in non-charter schools. Teachers' perceptions about working conditions in the opposite sector, as reported by

Maloney and McKenzie-Thompson (2013), align with the ideologies espoused by TFA and TFA corps members (Kretchmar, 2014). Thus, while teachers may want similar things from their certification programs, the programs themselves may play a key role in influencing how teachers structure their job search with respect to sector.

While the segmented labor market theory provides a useful lens with which to understand how teachers navigate the educational job market, there is other research suggesting that alternative certification and charter schools form a parallel education structure within the public education system. In New York City, for example, alternatively certified teachers work in charter schools and then pursue graduate degrees in education from programs aligned with charter schools (Mungal, 2016; Stitzlein & West, 2014). It is plausible that the alignment of these neoliberal structures is responsible for divisions in the educational labor market observed elsewhere, particularly considering that one consistent reason why some teachers prefer charter schools to non-charter public schools is that their ideological beliefs are aligned (Cannata, 2011; Jabbar et al., 2019). Charter schools and alternative certification pathways are neoliberal reforms established in counterpoint to the "traditional" public education system. Given ideological alignment between teachers from alternative certification and charter schools, in addition to the structural differences between these reforms and both traditional certification programs and non-charter public schools, it is important to investigate whether the dynamics affecting teachers and the division of labor in charter and non-charter public schools differ by teacher preparation pathway. The intersecting ideological and practical nature of these reforms necessitate that researchers better understand the ways in which these two reforms jointly impact teachers' working conditions in schools.

DATA AND SAMPLE

The data analyzed in this study were made available through the Texas Education Research Center (ERC), which houses and maintains student and teacher level data for all public education institutions in Texas. The data available through the Texas ERC compromises one of the largest public education management information systems nationwide, with data from 1993 onward. Available data include student-level enrollment, demographic, graduation, and accountability data from the Texas Education Agency (TEA); teacher-level course-assignment and employment data from the TEA; teacher certification data from the State Board of Educator Certification (SBEC); and enrollment and performance data for all students enrolling in Texas institutes of higher education from the Texas Higher Education Coordinating Board (THECB).

The specific data elements used in this study include student, demographic, accountability, and STEM enrollment data; teacher course assignment, certification, and demographic data; and campus and district level data with indicators for school type (e.g., charter or non-charter public), county, and region. The data analyzed come from the 2011-2012 academic year to the 2017-2018 academic year, all years for which it is possible to tie teachers to students in the Texas ERC. Figure 8 gives the number and proportion of teachers in the sample by sector, certification pathway, and academic year. The average demographic characteristics of students taught by alternatively and traditionally teachers in charter and non-charter public schools are provided in Figure 9 and Figure 10.

As displayed in Figure 8, there are more alternatively certified secondary STEM teachers than teachers from standard certification programs in both charter and non-charter public schools, and the proportion of alternatively certified teachers in charter schools is higher than the proportion of alternatively certified teachers in non-charter schools. In addition, the number of alternatively certified teachers increased over the time period of the study in both sectors, while the number of standard teachers in charter schools remained constant and the number of standard teachers in non-charter schools decreased slightly.

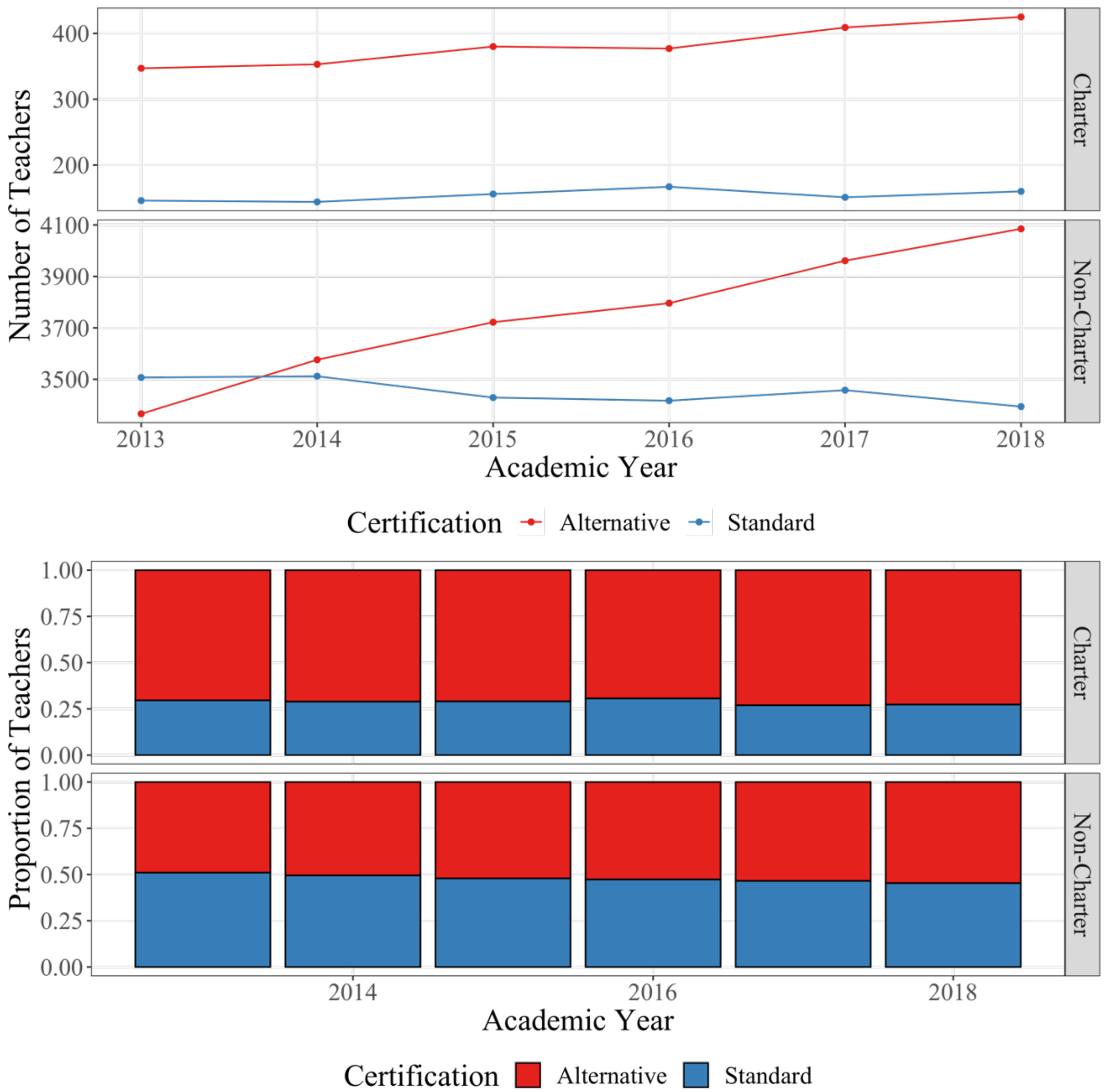

Figure 8. Number (top panels) and proportion (bottom panels) of STEM teachers by school sector and certification pathway for all years analyzed in this study.

Figure 9 shows how the racial demographics of classes taught by alternatively and traditionally certified teachers in charter and non-charter public schools differ. In non-charter public schools, traditionally certified teachers teach higher percentages of students who identify as Asian and White, while alternatively certified teachers teach classes with higher percentages of Black and Latinx students. There are no clear differences in the racial demographics of teachers in charter schools.

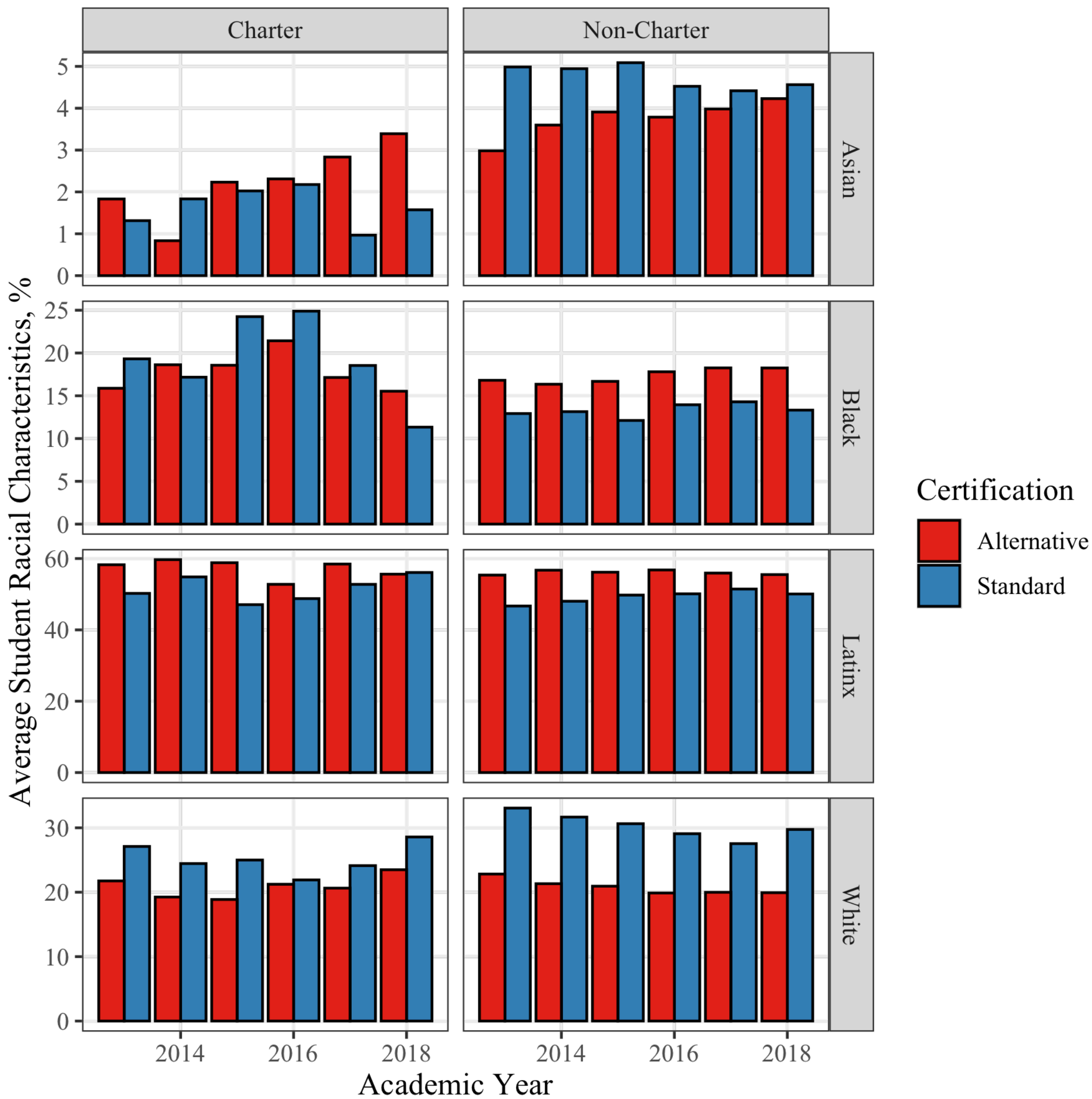

Figure 9. Average racial demographics of students in charter and non-charter school classrooms taught by alternatively and traditionally certified teachers.

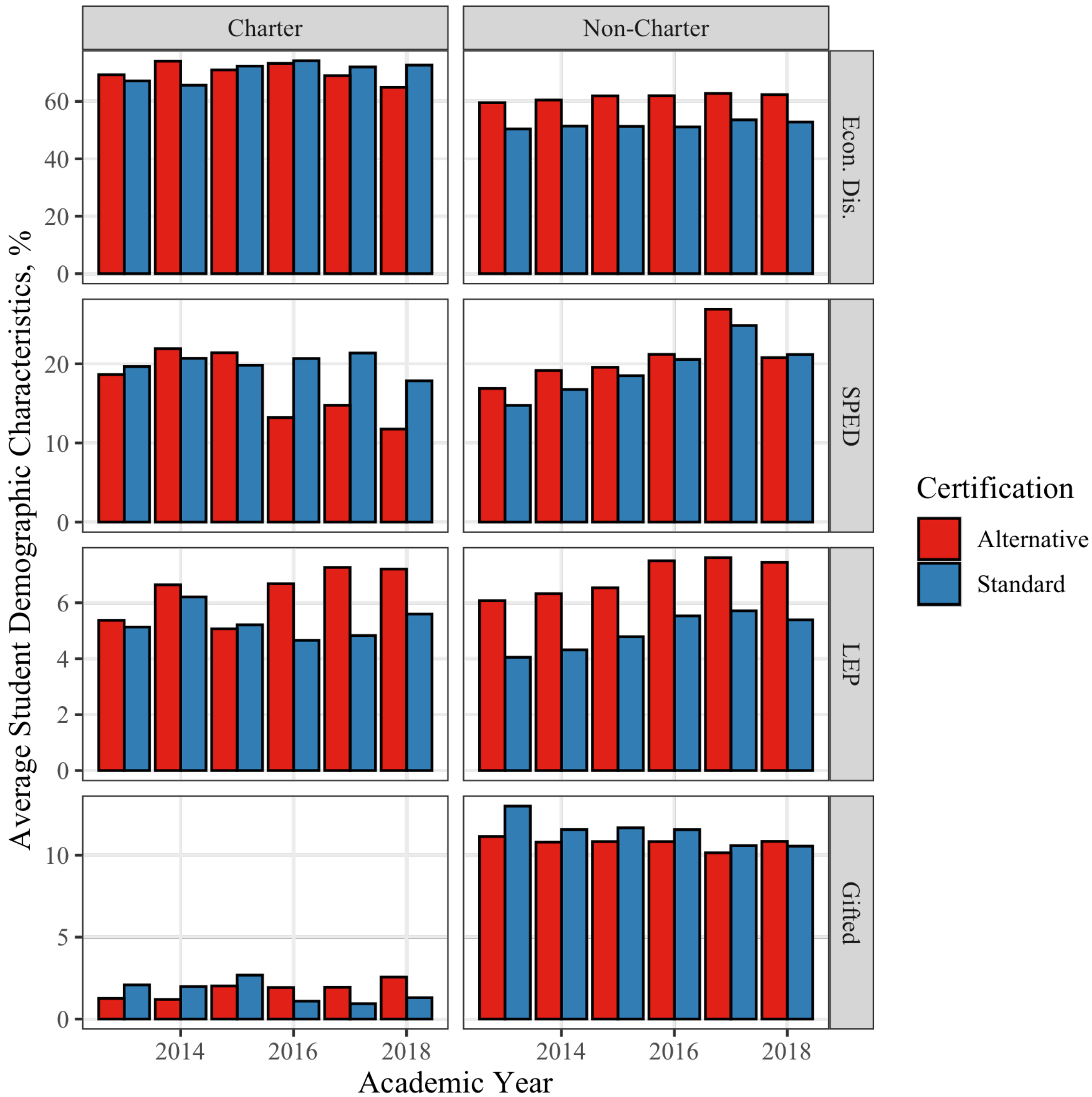

Figure 10. Average demographic characteristics of students in charter and non-charter school classrooms taught by alternatively and traditionally (standard) certified teachers.

Figure 10 provides insight into other substantive differences in classes taught by alternatively and traditionally certified teachers in charter and non-charter public schools. Non-charter public alternatively certified teachers are more likely to teach economically disadvantaged students and students designated as "Limited English Proficient," but these differences do not exist in charter schools. In addition, Figure 10 indicates that charter schools serve lower percentages of students identified as gifted and higher percentages of economically disadvantaged students.

Analyses are conducted at two levels, one that includes teachers who are assigned to teach any secondary STEM subjects and another in which the data are subset to include only teachers teaching high-stakes tested STEM subjects (algebra I and biology in Texas). For both analytical levels, average student demographics are computed for each class taught by a teacher and are included as covariates in the models predicting the likelihood of teacher transfer and the likelihood of specific transition pathways. At the second analytic level, in which teachers' demonstrated (in)ability to improve student performance on standardized exams is used to predict the likelihood of their course assignment trajectories, student test scores on standardized exams in algebra 1 and biology are used to compute value-added scores for each teacher. The specific ways by which this is accomplished are discussed in the "Analytic Methods" section.

In any given year, teachers are likely to teach more than one subject, and it is also presumable that the distribution of these subjects may change from year to year. Therefore, when analyzing a teacher's transition(s) to new courses, it was important to calculate the proportion of that teacher's instructional time that was assigned to a new course. To do so, a teacher's instructional time per class is weighted by one divided by the number of individual classes for which that teacher was the instructor of record in a given year. These class-level weights are then summed over by subject, so that it is possible to find the proportion of a teacher's instructional time dedicated to a particular STEM subject in a given year. Transition weights are computed by first determining the total percentage of a teacher's instructional time that is dedicated to the same subject from one year to the next.

Then the remaining percentage of a teacher's instructional time per subject is divided evenly between any new subjects in the subsequent year.

As an example, consider a teacher responsible for 6 classes at a given school. In the first year, assume this teacher is assigned to teach three sections of algebra 1 and three sections of geometry. In the second year, this teacher is assigned to teach two sections each of algebra 1, algebra 2, and pre-calculus. One-third of this teacher's instructional time remains the same from one year to the next (two sections of algebra 1). The instructional time dedicated to the third section of algebra 1 and three sections of geometry in the first year is then evenly divided between the two sections of algebra 2 and pre-calculus in the subsequent year.

There are several kinds of charter schools in Texas: open-enrollment (which are established by educational management organizations, non-profit organizations, and other eligible entities), university-sponsored charter schools, and campus-program charter schools, in which that school is established by a local school district. This study restricts analysis to open-enrollment charter schools. Since charter schools do not operate in all Texas counties, schools are only included in the present study if they are located in counties in which at least one charter school and at least one non-charter school operate. In addition, because this study is interested in how teachers are assigned to teach secondary STEM courses, only the fraction of a teacher's instructional time allocated for secondary STEM courses is included in analyses (e.g., if a teacher is assigned to teach both 8^{th} and 9^{th} grade STEM courses, only that teacher's 9^{th} grade STEM course assignment would be analyzed).

ANALYTIC METHODS

As mentioned previously, analyses are conducted at two levels, each discussed in detail here. At the first analytic level, models are constructed to explore how teachers are assigned to teach all secondary STEM subjects in addition to the likelihood that a teacher continues to teach the same subject. The goal of the second analysis is to evaluate how teacher effectiveness influences teacher assignment to STEM subjects. One proxy for teacher effectiveness is their ability or inability to improve student scores on standardized assessments. In high schools, standardized assessments in STEM are only administered for algebra I and biology, both of which are typically taken in students' 9th grade year. As such, to evaluate the relationship between teacher effectiveness and course-assignment in charter and non-charter schools, the second analytic level restricts the teacher sample to teachers for which it is possible to compute value-added scores in algebra I and biology.

General Assignment to STEM Courses

The first model used to explore teacher assignment is a logistic regression predicting the likelihood that a teacher is assigned to teach the same course at the same campus in the subsequent year as a function of working in a charter school, coming from an alternative certification pathway, their interaction, average classroom demographics, and teacher characteristics. This model is specified by Equation (7):

$$log\left(\frac{p_{i,t}}{1-p_{i,t}}\right) = \beta_C C_{i,t'} + \beta_P P_i + \beta_{CP} C_{i,t'} P_i + \beta_X \boldsymbol{X_{i,t'}} + \beta_{t'} t' + County_{i,j,t'} \qquad (7)$$

In Equation (7), $p_{i,t}$ is the probability that teacher *i* continues to teach the same STEM course in year *t*, C_i is a binary variable indicating whether or not teacher *i* worked in a charter school in the prior year t' ($t' = t - 1$), P_i is a binary variable indicating whether or not teacher *i* was prepared in an alternate certification program, $\boldsymbol{X_i}$, is a vector of demographic variables giving the average demographic characteristics of teacher *i*'s students in year t' in addition to that teacher's demographics, t' is a fixed effects term for prior year, and *County* is a fixed effects term for the county in which campus *j* is located.

Two variants of this model are run: one in which the sector, certification interaction term is included and another in which the interaction term is excluded.

In addition to evaluating the probability that a teacher continues to teach the same STEM subject in a subsequent year, a multinomial logistic regression model is constructed to evaluate the probability of a teacher being assigned to teach different kinds of STEM courses from one year to the next. STEM courses in Texas are categorized into the following: *advanced* courses; high-stakes *tested* courses; non-advanced *elective* courses, and exit from teaching (or, more specifically, exit from the data set—a teacher could have moved out of state or gained employment in a private school). The probability of a teacher i being assigned to teach course of type α relative to the reference category in year t is estimated as a function of several predictor variables, including teaching in a charter school, preparation pathway, their interaction, a teacher's prior year course assignment, and teacher and student demographic characteristics, as specified by Equation (8). This model estimates how these covariates affect a teacher's likelihood of transitioning to different kinds of STEM courses.

$$log\left(\frac{p_{i,t}^{\alpha}}{p_{i,t}^{ref}}\right) = \beta_C C_{i,t'} + \beta_P P_i + \beta_{CP} C_{i,t'} P_i + \beta_X \boldsymbol{X_{i,t'}} + \beta_S Crs_{i,t'} + \beta_{t'} t' + County_{i,j,t'} \quad (8)$$

In Equation (8), the predictor variables are the same as those in Equation (7), except for now a categorical variable indicating the type STEM course teacher i taught in year t' is also included ($Crs_{i,t'}$). By including this variable, it is possible to evaluate how the probability of teaching a certain kind of STEM course in a subsequent year depends upon the kind of STEM course to which a teacher was assigned in the prior year. As with the logistic model, this model is run with the interaction effect included and excluded. In addition, this model is run using two different subsets of the data: one with the full dataset and another in which the data set is restricted to teachers who are not assigned to teach the same course at the same campus in a subsequent year. In the latter case, a binary indicator for whether or not a teacher stays at their campus from t' to t is included.

Teacher Value-Added and Course Assignment

At the second analytic level, models are constructed in order to evaluate how teacher effectiveness affects the likelihood of that teacher being reassigned to teach the same subject in a subsequent year and to investigate how a teacher's effectiveness mediates the likelihood of that teacher transitioning to another course. As such, value added scores for algebra 1 and biology teachers are calculated using the hierarchical model specified by Equation (9):

$$S_{i,t} = \beta_1 S_{i,t'} + \beta_2 S_{i,t'}^2 + \beta_3 S_{i,t'}^3 + T_{j[i]} + C_{k[i]} + Cls_{m[C[i]]} + \sum_g \chi_{g[i]} + \epsilon_i \qquad (9)$$

Here, $S_{i,t}$ represents the end-of-course exam score for student i in year t, and $S_{i,t'}$ is a pretest score for student i in year t' ($t' = t - 1$) modeled to first, second, and third order. Random effects coefficients are generated for teachers T, campuses C, and classes Cls. Controls for student demographic characteristics, $\chi_{g[i]}$, are also included as flags indicating membership (indexed by g) in the following groups: gifted education; special education; race/ethnicity; economic disadvantage (determined by eligibility for free and reduced lunch); and designation as limited English proficient (LEP). Individual teacher coefficients generated in this model are used as teachers' value-added scores. The value-added coefficients for teachers are then included as additional predictor variables in the logistic and multinomial logistic regression models specified by Equations (7) and (8). In addition to teacher value-added coefficients, some variants also include campus-level value-added coefficients as predictors to also include controls for campus quality.

At the second analytic level, all models are constructed both with and without a certification and sector interaction term. As at the first analytic level, the multinomial models with value-added predictors are analyzed using all teachers for whom it was possible to compute a value-added score and sub-setting the data set to include only teachers who do not teach the same course at the same campus in a subsequent year. In addition, these models are used to analyze algebra 1 and biology teachers both separately and jointly.

RESULTS

In this section, results are presented for each analytic level, with results from models exploring teacher assignment to all STEM courses presented first and models exploring how teacher effectiveness influences subsequent STEM course assignment presented second.

Assignment to Secondary STEM Courses

Coefficients from the logistic regression model predicting the likelihood of a STEM teacher continuing to teach the same STEM course at the same campus in a subsequent year, as specified by Equation (7), are provided in Table 6. Model specifications in which the certification/sector interaction are both included and excluded are provided. The coefficients in Table 6 can be used to calculate the associated change in probability of a teacher continuing to teach the same course at the same campus in a subsequent year given the predictor variable (displayed in Figure 11).

Statistically significant effects for alternative certification and employment in a charter school are obtained, suggesting that alternatively certified teachers are approximately 10% less likely than traditionally certified STEM teachers to be assigned to teach the same course at the same campus in a subsequent academic year. Employment in a charter school is associated with a decrease of between 43% and 48% (when the interaction is not included or is included, respectively) in the likelihood of a teacher being assigned to teach the same STEM course at the same school in a subsequent year. The certification/sector term is not statistically significant; however, including this term increases the magnitude of the charter school coefficient.

Table 6. Coefficients from a logistic regression model predicting the probability of a teacher being assigned to teach the same STEM course at the same campus in a subsequent year.

		Including Interaction			**Without Interaction**		
	Coefficients	**Est.**	**S.E.**	**Sig.**	**Est.**	**S.E.**	**Sig.**
	Intercept	0.77	0.20	***	0.77	0.20	***
	Alt. Cert.	-0.11	0.03	***	-0.11	0.03	***
	Charter	-0.65	0.11	***	-0.57	0.06	***
	Interaction	0.11	0.12		---	---	---
Avg. Classroom Demog.	Female	0.39	0.09	***	0.39	0.09	***
	Asian	0.51	0.17	**	0.51	0.17	**
	Black	-0.68	0.11	***	-0.68	0.11	***
	Latinx	-0.22	0.10	*	-0.22	0.10	*
	Econ. Dis.	-0.24	0.08	**	-0.24	0.08	**
	Gifted	0.33	0.09	***	0.34	0.09	***
	LEP	-0.89	0.15	***	-0.89	0.15	***
	SPED	-0.67	0.06	***	-0.67	0.06	***
Teacher Demog.	Female	-0.04	0.03		-0.04	0.03	
	Black	-0.05	0.07		-0.05	0.07	
	Other Race	-0.02	0.11		-0.02	0.11	
	Latinx	-0.12	0.07	.	-0.12	0.07	.
	White	-0.02	0.06		-0.02	0.06	

*** p < 0.001, ** p < 0.01, * p < 0.05, . p < 0.10
Interaction refers to the interaction between certification and sector.

In addition to statistically significant coefficients for alternative certification and charter school employment, the demographic compositions of teachers' classrooms are also associated with statistically significant changes in the probability of teachers being assigned to teach the same STEM subject at the same school in a subsequent year. Student demographic variables represent the proportion of a teacher's class characterized by that demographic. Thus, coefficients give the associated probability of a teacher continuing to teach the same STEM course at the same school if they taught an entire class (or set of classes) characterized by the indicated demographic variable. For example, teaching a class in which all students are economically disadvantaged is associated with a 21% decrease in the likelihood of that teacher continuing to teach the same STEM subject at the same school in a subsequent year.

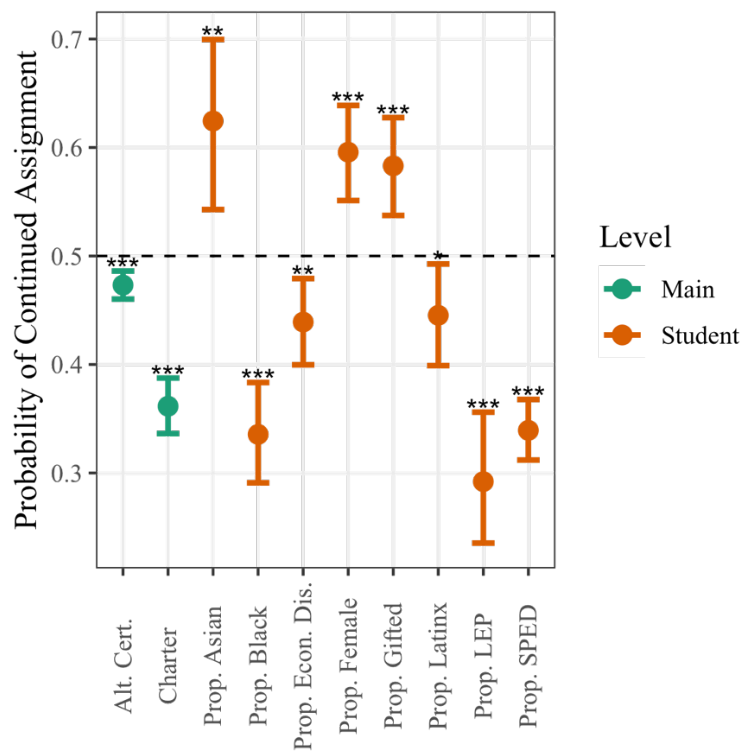

Figure 11. Probability estimates from logistic regression model predicting the likelihood that a teacher continues to teach the same STEM course at the same campus from one year to the next given sector employment, certification, and classroom demographics.

Coefficients from this model indicate that teachers with classes consisting of higher proportions of students identifying as Black or Latinx or who are identified as economically disadvantaged, LEP, or SPED are associated with statistically significant decreased probabilities of teaching the same STEM course at the same campus in a subsequent year. By contrast, teachers with classes consisting of higher proportions of students identifying as Asian or students classified as gifted are associated with increased probabilities of teaching the same STEM course at the same school in subsequent years.

Table 7. Coefficients from a multinomial regression model predicting the probability of teachers being assigned to teach specific types of STEM courses in a subsequent year. These results include all teachers in the sample analyzed.

		Adv. to Elective			**Tested to Elective**			**Left to Elective**		
	Coefficients	**Est.**	**S.E.**	**Sig.**	**Est.**	**S.E.**	**Sig.**	**Est.**	**S.E.**	**Sig.**
	Intercept	-2.82	0.37	***	-3.53	0.46	***	-2.28	0.29	***
	Alt. Cert.	-0.18	0.05	***	-0.04	0.06		-0.04	0.04	
	Charter	0.10	0.11		0.34	0.12	**	0.90	0.07	***
	Adv. Course	3.83	0.05	***	1.33	0.08	***	1.47	0.05	***
	Tested Course	1.75	0.30	***	3.37	0.18	***	1.68	0.21	***
Avg. Classroom Demog.	Female	0.53	0.18	**	-0.17	0.19		0.13	0.13	
	Asian	0.92	0.28	**	0.03	0.45		-0.19	0.29	
	Black	-0.02	0.21		0.60	0.22	**	0.42	0.15	**
	Latinx	0.17	0.19		0.24	0.21		0.14	0.14	
	Econ. Dis.	-0.44	0.16	**	0.30	0.17	.	0.26	0.12	*
	Gifted	1.23	0.16	***	-0.42	0.27		0.33	0.17	.
	LEP	-0.72	0.34	*	0.55	0.26	*	0.54	0.20	**
	SPED	-0.77	0.19	***	0.64	0.11	***	0.58	0.08	***
Teacher Demog.	Female	0.06	0.05		0.46	0.06	***	0.15	0.04	***
	Black	-0.34	0.14	*	0.23	0.16		0.02	0.10	
	Other Race	-0.26	0.21		-0.11	0.26		-0.10	0.16	
	Latinx	-0.25	0.12	*	0.35	0.15	*	-0.15	0.10	
	White	-0.14	0.11		0.00	0.14		0.02	0.09	

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, . $p < 0.10$

Coefficients from the multinomial logistic regression model specified by Equation (8) are provided in Table 7 and Table 8. Visualizations of the exponentiated coefficients for these models are provided in Figure 12 and Figure 14. This regression model predicts the likelihood of a teacher's transition pathway between STEM courses (e.g., that a teacher is assigned to teach an advanced STEM course, tested STEM course, or leave the profession relative to being assigned to teach an elective STEM course) from one year to the next. Coefficients in Table 7 and Figure 12 are obtained when the model is applied to all secondary STEM teachers, and coefficients in Table 8 and Figure 14 are obtained when the data are subset to include only teachers who do not teach the same course at the same campus in the subsequent year. Sankey diagrams depicting course reassignment pathways are provided for these two subsets in Figure 13 and Figure 15, respectively. Another variant of the regression models included a certification/sector interaction term, but the interaction term was not statistically significant and increased the magnitude of the coefficients for charter schools. As such, results from the latter model variants are not reported.

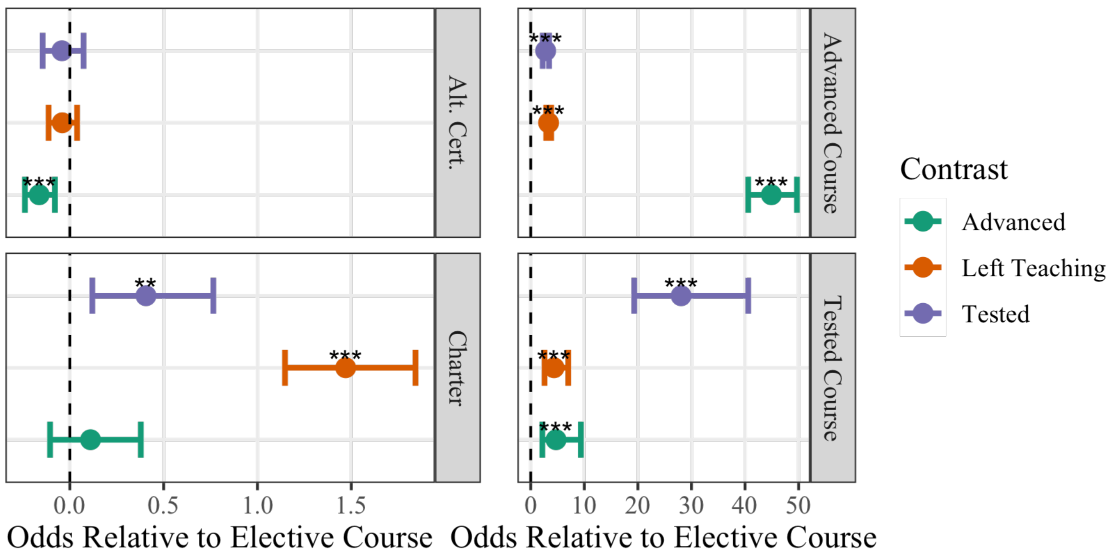

Figure 12. Odds of all teachers being assigned to teach a certain STEM course given sector employment, certification, and prior year assignment.

A statistically significant coefficient for certification indicates that alternatively certified teachers are 16% less likely than traditionally certified teachers to be assigned to teach an advanced STEM course relative to an elective STEM course in a subsequent year. Alternative certification is not associated with statistically significant differences in the likelihood of that teacher being assigned to a tested STEM course or leaving the profession in a subsequent year.

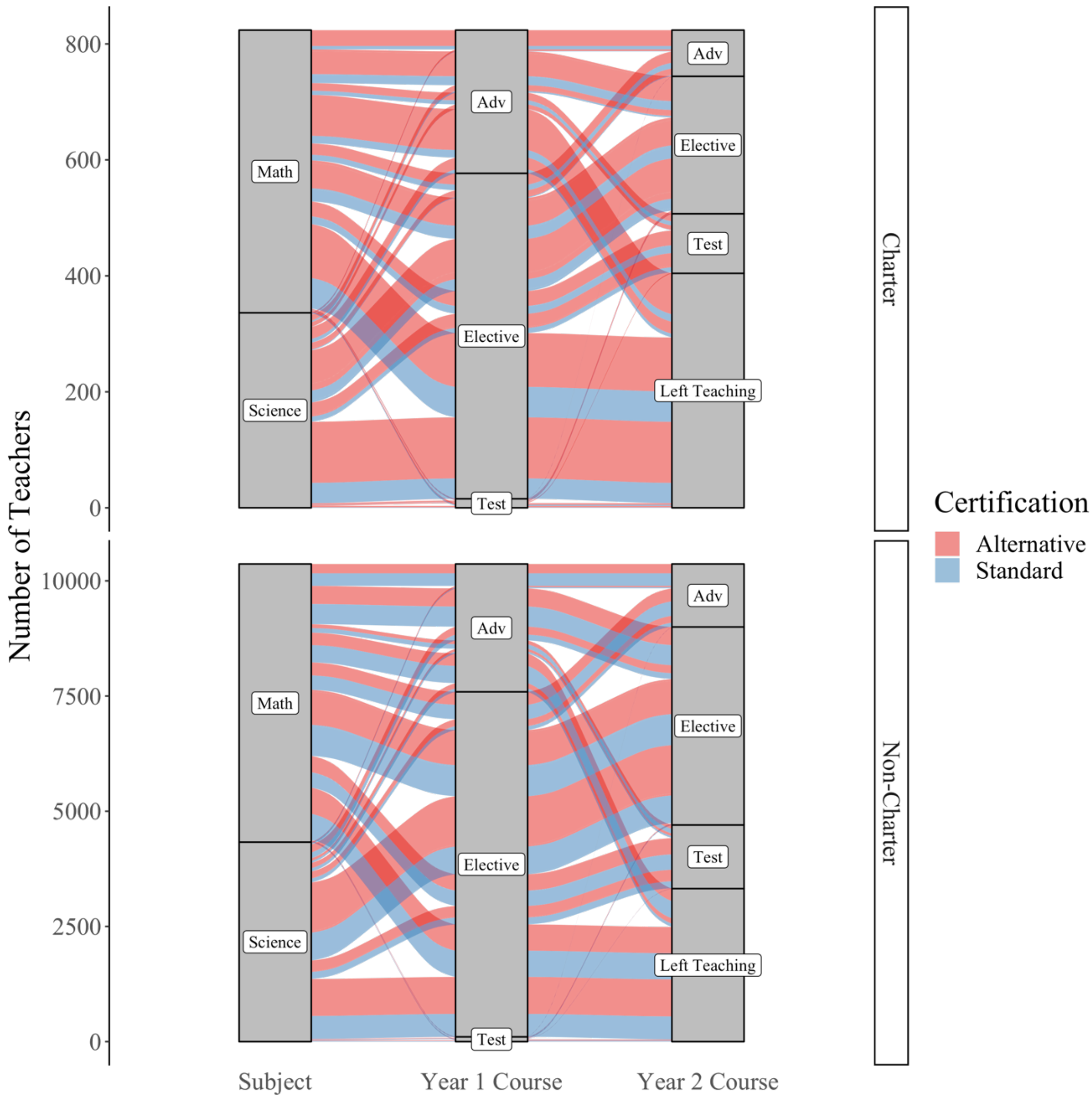

Figure 13. Sankey diagram illustrating how STEM teachers are reassigned to different courses in secondary schools. Color represents certification pathway and panels indicate sector employment.

Relative to teaching an elective STEM course in a subsequent year, teaching in charter schools is associated with 40% and 9% increases in the likelihood of being assigned to teach tested STEM courses or leaving the profession, respectively, in the subsequent year. Teaching an advanced STEM course or a tested STEM course is associated with statistically significant increases in the likelihood of teaching an advanced or tested STEM course in the following year in addition to statistically significant increase in the likelihood of leaving the profession. Coefficients are particularly large when the transition pathway matches a teacher's prior year assignment, likely indicating that teachers are often assigned to teach the same STEM courses from one year to the next.

Table 8. Coefficients from a multinomial regression model predicting the probability of teachers being assigned to teach a specific type of STEM course in a subsequent year. These results are subset to teachers who were not assigned to teach the same STEM course at the same campus in a subsequent year.

		Adv. to Elective			**Tested to Elective**			**Left to Elective**		
	Coefficients	**Est.**	**S.E.**	**Sig.**	**Est.**	**S.E.**	**Sig.**	**Est.**	**S.E.**	**Sig.**
	Intercept	-1.32	0.49	**	-1.6	0.51	**	1.33	0.61	*
	Alt. Cert.	-0.23	0.06	***	-0.14	0.06	*	-0.36	0.07	***
	Charter	0.28	0.13	*	0.21	0.13	.	0.11	0.11	
	Adv. Course	0.44	0.07	***	-0.09	0.08		0.40	0.09	***
	Tested Course	-0.14	0.4		0.02	0.29		0.64	0.35	.
	Same Campus	0.50	0.08	***	-0.11	0.07		-21.7	250	
Avg. Classroom Demog.	Female	0.30	0.21		0.06	0.19		0.41	0.21	.
	Asian	-0.12	0.38		-0.08	0.46		0.25	0.50	
	Black	0.14	0.26		0.21	0.23		-0.49	0.24	*
	Latinx	0.25	0.23		0.10	0.22		0.10	0.23	
	Econ. Dis.	-0.40	0.19	*	0.23	0.18		-0.10	0.20	
	Gifted	0.99	0.21	***	-0.24	0.27		-0.02	0.28	
	LEP	-0.50	0.39		0.01	0.29		0.07	0.35	
	SPED	-1.23	0.21	***	0.28	0.12	*	1.04	0.17	***
Teacher Demog.	Female	0.04	0.06		0.48	0.06	***	0.10	0.07	
	Black	-0.39	0.17	*	0.26	0.17		-0.13	0.18	
	Other Race	-0.39	0.27		-0.15	0.28		-0.35	0.28	
	Latinx	-0.30	0.15	*	0.25	0.16		-0.41	0.17	*
	White	-0.20	0.14		-0.02	0.15		-0.11	0.16	

*** p < 0.001, ** p < 0.01, * p < 0.05, . p < 0.10

Table 8 provides coefficients indicating how variables influence the likelihood of a teacher transitioning to a different STEM course when that teacher is not assigned to teach the same course at the same school in a subsequent academic year. When analyzing teachers who do not teach the same STEM course at the same campus from one year to the next, alternatively certified teachers are less likely than traditionally certified teachers to be reassigned to advanced or tested STEM courses. In addition, this subset of alternatively certified teachers is less likely to leave the profession than traditionally certified teachers. Among this subset of teachers, employment in a charter school is associated with a 32% increase in the likelihood of a teacher being assigned to teach an advanced STEM course in the subsequent year. Teaching an advanced STEM course is associated with 55% increase in the likelihood of a teacher teaching an advanced STEM course (either a different subject or at a new school) in the subsequent year and a 49% increase in the likelihood of that teacher leaving the profession. Staying at the same campus from one academic year to the next is associated with a 65% increase in the likelihood of that teacher being assigned to an advanced STEM course as opposed to an elective STEM course.

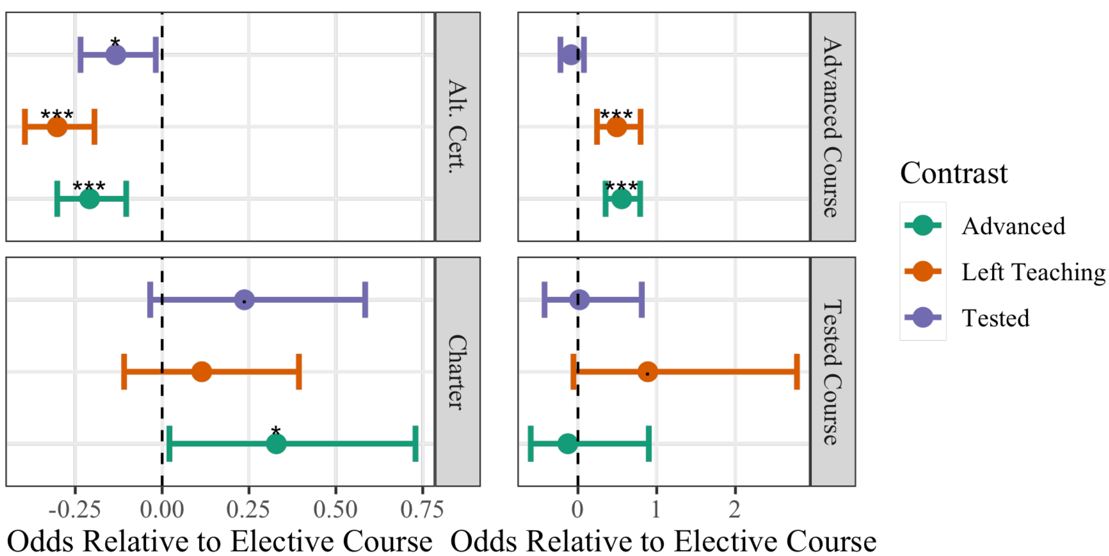

Figure 14. Odds that teachers who are reassigned to different courses are assigned to specific types of STEM courses given sector employment, certification pathway, and prior year STEM assignment.

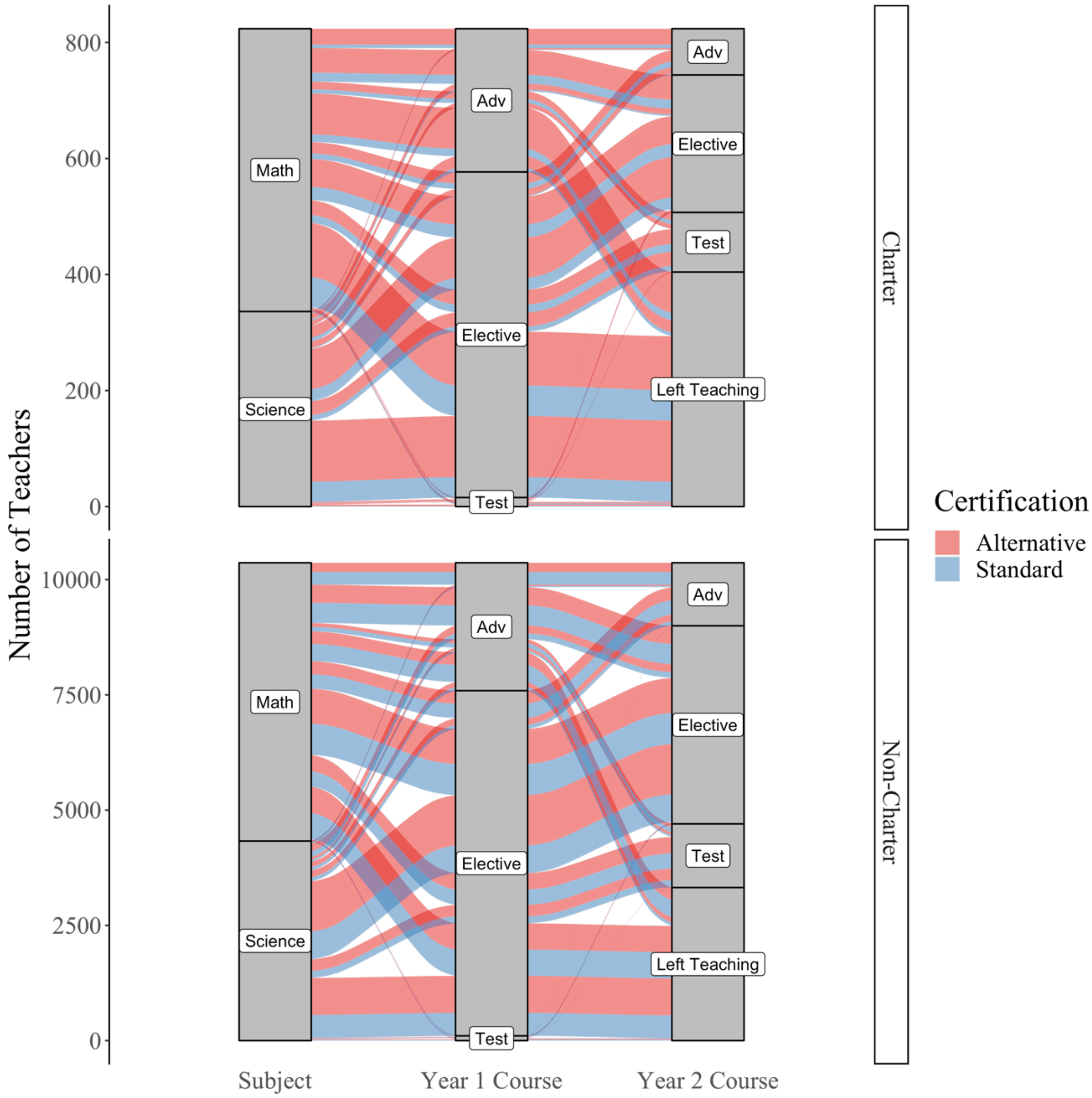

Figure 15. Sankey diagram depicting how STEM teachers are reassigned when they do not teach the same STEM course from one year to the next. Color indicates certification pathway and panel indicates sector employment.

Teacher Effectiveness and STEM Course Assignment

At the second analytic level, models are constructed to evaluate how a teacher's demonstrated (in)ability to improve student test scores on high-stakes standardized assessments in STEM subjects influences the likelihood of that teacher being assigned to teach different STEM courses. This is accomplished by including value-added coefficients computed by the hierarchical linear model given by Equation (9) as predictor variables in the logistic regression and multinomial logistic regression models specified by Equations (7) and (8). Models are constructed to analyze algebra 1 and biology teachers both separately and jointly, and one variant of each model includes a campus-level value-added coefficient as a predictor variable in addition to teacher-level value-added coefficients to control for campus quality. Models control for the same demographic characteristics as those constructed at the first analytic level; however, for ease of interpretation only coefficients for certification, school sector, teacher and campus value-added (labeled *Teacher* and *Campus*, respectively, in the coefficient tables), and prior year course type are reported.

Table 9. Coefficients from logistic regression models predicting the likelihood of a teacher continuing to teach the same STEM subject at the same campus in a subsequent year as a function of that teacher's value-added coefficient in the prior year. Variants are run for algebra 1 and biology teachers separately and jointly in addition to controlling for only teacher quality and controlling for both teacher and campus quality.

		Teacher Only			Teacher and Campus		
	Coefficients	**Est.**	**S.E.**	**Sig.**	**Est.**	**S.E.**	**Sig.**
Algebra 1	Alt. Cert.	-0.16	0.13		-0.15	0.13	
	Charter	-0.15	0.19		-0.13	0.19	
	Teacher	0.38	0.17	*	0.34	0.18	.
	Campus	---	---	---	0.12	0.12	
Biology	Alt. Cert.	-0.26	0.16		-0.26	0.16	
	Charter	-0.43	0.21	*	-0.44	0.21	*
	Teacher	0.1	0.23		0.11	0.25	
	Campus	---	---	---	-0.03	0.18	
Tested STEM	Alt. Cert.	-0.19	0.1	*	-0.19	0.1	*
	Charter	-0.28	0.14	*	-0.28	0.14	*
	Teacher	0.04	0.09		0.03	0.16	
	Campus	---	---	---	0.00	0.15	

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, . $p < 0.10$

As with results reported earlier, exponentiating coefficients provided in Table 9 gives the associated change in the odds that a teacher will continue to teach the same STEM subject at the same campus in a subsequent year for each predictor variable. Teachers' value-added coefficients are the only statistically significant predictors of continued likelihood of teaching the same STEM course in the algebra 1 model when the campus-level value-added coefficient term is not included. This coefficient indicates that a standard deviation increase in an algebra 1 teacher's value added score is associated with a 46% increase in the likelihood of that teacher continuing to teach the same STEM subject at the same campus in the following year. Models including campus-level value-added coefficients as predictor variables indicate that campus quality is not statistically significantly related to the likelihood of teachers continuing to teach the same STEM course at those campuses. Teaching in a charter school is associated with a decreased likelihood of teaching the same course at the same campus in a subsequent year in the models limited to biology teachers and including all teachers in tested STEM subjects, although the latter result is likely driven by biology teachers. In the model that includes all STEM teachers, alternative certification is associated with statistically significant decreases in the likelihood that a teacher continues to teach the same STEM course at the same campus in a subsequent year.

Multinomial regression models predicting the likelihood of teachers of tested STEM subjects being assigned to different kinds of STEM courses in the subsequent academic year as a function of their computed value-added scores are provided in Table 10. As with the logistic regression model, the multinomial regression models are constructed for algebra 1 and biology teachers separately and jointly. In these models, teachers' prior year value-added scores are positively associated with the likelihood of teachers being assigned to teach advanced and tested STEM subjects relative to the likelihood of being assigned to teach an elective STEM course in the subsequent year.

However, this association is only statistically significant for the tested to elective STEM course contrast in the model analyzing biology teachers.

Table 10. Results from multinomial models predicting the likelihood of being assigned to teach specific types of courses as a function of certification pathway, sector, prior year value-added, and prior year STEM course assignment.

		Adv. to Elective			**Tested to Elective**			**Left to Elective**		
	Coefficients	**Est.**	**S.E.**	**Sig.**	**Est.**	**S.E.**	**Sig.**	**Est.**	**S.E.**	**Sig.**
Algebra 1	Alt. Cert.	-0.11	0.25		-0.15	0.19		0.37	0.21	.
	Charter	-0.05	0.37		-0.57	0.32	.	0.7	0.24	**
	Teacher	0.2	0.31		0.22	0.25		-0.49	0.27	.
	Adv. Course	3.47	0.26	***	1.17	0.25	***	1.05	0.25	***
	Tested Course	1.86	1.66		2.32	0.94	*	0.2	1.52	
Biology	Alt. Cert.	0.1	0.43		0.09	0.24		0.43	0.27	
	Charter	-0.08	0.66		-0.15	0.33		0.77	0.3	**
	Teacher	1.2	0.65	.	0.9	0.38	*	0.3	0.42	
	Adv. Course	5.22	0.46	***	2.39	0.39	***	2.19	0.39	***
	Tested Course	2.95	0.94	**	2.65	0.64	***	1.15	0.82	
Tested STEM	Alt. Cert.	-0.06	0.21		-0.06	0.14		0.38	0.16	*
	Charter	-0.13	0.32		-0.39	0.23	.	0.7	0.19	***
	Teacher	0.09	0.19		0.1	0.13		-0.03	0.14	
	Adv. Course	4.03	0.22	***	1.54	0.2	***	1.44	0.21	***
	Tested Course	2.53	0.76	***	2.49	0.52	***	0.94	0.7	

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, . $p < 0.10$

As with results from the first analytic-level including all secondary STEM teachers, the type of STEM course to which a teacher is assigned in a prior year is a statistically significant predictor of the likelihood of the kind of STEM course to which that teacher is assigned in the subsequent year. Teaching an advanced STEM course in a prior year is associated with increased probabilities of being assigned to teach an advanced or tested STEM course in the following year in addition to increased probabilities of leaving the profession. This result holds for all models. In most models (all but the advanced to elective contrast for algebra 1 teachers), being assigned to teach a tested STEM subject in a prior year is associated with statistically significant increase in the likelihood of teaching advanced and tested, as opposed to elective, STEM courses in the subsequent year. Employment in a charter school, by contrast, is associated with statistically significant increases in the likelihood of teachers leaving the profession as opposed to teaching an elective STEM course in the subsequent year.

Table 11. Multinomial regression coefficients predicting the likelihood of teachers being assigned to teach certain STEM courses as a function of certification, sector, prior year teacher and campus value-added coefficients, and prior year STEM course assignment.

		Adv. to Elective			Tested to Elective			Left to Elective		
	Coefficients	**Est.**	**S.E.**	**Sig.**	**Est.**	**S.E.**	**Sig.**	**Est.**	**S.E.**	**Sig.**
Algebra 1	Alt. Cert.	-0.09	0.25		-0.14	0.19		0.36	0.21	.
	Charter	-0.02	0.38		-0.57	0.32	.	0.68	0.25	**
	Teacher	0.05	0.32		0.2	0.26		-0.43	0.28	
	Campus	0.36	0.23		0.04	0.19		-0.15	0.19	
	Adv. Course	3.49	0.26	***	1.17	0.25	***	1.05	0.25	***
	Tested Course	1.98	1.66		2.32	0.94	*	0.18	1.52	
Biology	Alt. Cert.	0.1	0.43		0.1	0.24		0.44	0.27	
	Charter	-0.08	0.67		-0.1	0.33		0.78	0.3	**
	Teacher	1.04	0.67		0.74	0.4	.	0.25	0.45	
	Campus	0.44	0.52		0.35	0.28		0.08	0.29	
	Adv. Course	5.19	0.46	***	2.39	0.39	***	2.19	0.39	***
	Tested Course	2.95	0.94	**	2.64	0.64	***	1.16	0.82	
Tested STEM	Alt. Cert.	-0.05	0.21		-0.06	0.14		0.38	0.16	*
	Charter	-0.12	0.32		-0.39	0.23	.	0.7	0.19	***
	Teacher	-0.25	0.33		0.09	0.23		-0.01	0.25	
	Campus	0.38	0.3		0.00	0.22		-0.02	0.23	
	Adv. Course	4.04	0.22	***	1.54	0.2	***	1.44	0.21	***
	Tested Course	2.54	0.76	***	2.49	0.52	***	0.94	0.7	

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, . $p < 0.10$

The multinomial logistic regression coefficients reported in Table 11 predict the likelihood of teachers transitioning to certain kinds of STEM courses as a function of certification, employment in a charter school, prior year course assignment category, and both teacher and campus quality. As with coefficients reported for models including only terms for teacher value-added in the prior year, results in Table 11 indicate that a teacher's value-added score is not a statistically significant predictor of the kind of course to which that teacher is assigned in a subsequent year when other covariates are included. In addition, there is no statistically significant relationship between campus value-added and the probability of being assigned to teach a certain kind of STEM course in a subsequent academic year.

Rather than teacher or campus quality, the type of STEM course to which a teacher is assigned in a prior year is a statistically significant predictor of the type of course to which that teacher is assigned in a subsequent year. Teaching an advanced STEM subject is associated with increased probabilities of being assigned to teach advanced or tested STEM courses in the subsequent year in addition to an increased likelihood of leaving the teaching profession. Teaching a tested STEM subject is associated with an increased likelihood of being assigned to teach advanced or tested STEM subjects in the subsequent year (the exception is in the advanced to elective contrast for algebra 1 teachers). In all models, employment in a charter school is associated with statistically significant increases in the probability of leaving the profession rather than being assigned to teach an elective STEM course in the subsequent year, and in the model including teachers from all tested STEM subjects, alternative certification is also associated with an increased probability of leaving the profession.

DISCUSSION

At the first analytic level in which teacher assignment to all STEM courses was explored as a function of teacher certification and charter school employment, results suggest that alternative certification and employment in a charter school are both associated with higher probabilities of mobility, either reassignment to a new course, moving to a new school, or leaving the profession entirely (Table 6). In addition, teachers in classes comprised of higher percentages of students from ethnic minority populations that have been historically underrepresented in STEM disciplines and with higher concentrations of economically disadvantaged students are also associated with decreased likelihood of continuing to teach the same STEM subject at the same school from one year to the next. Taken together, these findings are of particular concern, because market-based reforms that are disproportionately targeted towards serving ethnic minority and economically disadvantaged populations may exacerbate low teacher retention among populations for whom high teacher mobility is already a problem.

Multinomial regression models exploring teacher assignment in general and exploring teacher assignment in cases when teachers are not assigned to teach the same course at the same campus from one year to the next provide additional insight into how market-based reforms influence STEM teachers' course assignments. The multinomial model exploring all STEM course assignment dynamics (Table 7) indicates that, compared to traditionally (or standard) certified teachers, alternatively certified teachers have a lower probability of being assigned to advanced STEM courses than they do of being assigned to elective STEM courses. In addition, charter school teachers have higher probabilities both of being assigned to teach tested STEM subjects and of leaving the profession than of being assigned to teach elective STEM subjects. Thus, charter schools are associated with higher teacher turnover, a finding that is consistent with other literature. Moreover, that charter schools are associated with increased probabilities of being assigned to tested STEM subjects instead of elective STEM subjects may be due to the fact that charter schools have more limited course offerings (and offer fewer elective STEM courses in general) or that the teachers being assigned to tested STEM subjects are replacing teachers who leave the profession.

Other significant results from the multinomial model exploring all STEM course assignment dynamics indicate prior year course assignment in advanced and tested STEM subjects is associated with higher probability of being assigned to advanced or tested STEM courses in the following year or of leaving the profession. This is an interesting finding, as it suggests that the set of teachers assigned to teach advanced and tested STEM subjects is different from the set assigned to teach elective STEM subjects. Compared to elective STEM courses, advanced and tested courses have relatively higher stakes. It is not unreasonable to assume that teachers perceived as being of higher quality would be assigned to advanced or tested subjects by school leaders, while teachers perceived as being inferior are relegated to elective courses where inefficacy is harder to detect. The qualifications of teachers assigned to teach these different types of courses is an area for additional research.

Results from the multinomial model exploring how teachers are reassigned when they do not teach the same STEM course at the same campus from one year to the next may provide a partial answer. For all contrasts, alternative certification is associated with a statistically significant higher probability of being assigned to an elective STEM course rather than being assigned to an advanced or tested STEM course or of leaving the profession. Given this, it is presumable that certification pathway is one characteristic that distinguishes the set of teachers assigned to either advanced or tested STEM courses from the set assigned to elective courses. Another finding from this model indicates that prior assignment to an advanced STEM course is associated with increased probability of being assigned to a different advanced STEM course at the same school or to the same STEM course at a different school in addition to an increased probability of leaving the profession relative to elective courses. Existing literature suggests that more desirable courses, such as advanced STEM subjects, are given to teachers with higher seniority. Therefore, it is reasonable that the reason why prior assignment to an advanced STEM course is associated with increased probability of leaving the profession is that these teachers are closer to retirement.

A final important result from this model suggests that employment in a charter school is associated with increased likelihood of being assigned to an advanced course for teachers who do not teach the same course at the same campus from one year to the next. In general, charter school teachers have higher mobility between courses, so additional research into the reasons for which these teachers are more likely to move to different sets of advanced courses from one year to the next warrants additional research.

At the second analytic level, in which teacher and campus quality (as determined by value-added estimates) are used to predict course assignment for STEM teachers, neither teacher nor campus quality is found to be a statistically significant predictor of a teacher continuing to teach the same STEM course at the same campus from one year to the next or of the probability that a teacher is assigned to a certain kind of STEM course from one year to the next. This finding contradicts earlier findings that show teacher value added increases the likelihood of a teacher being assigned to teach the same tested STEM subject in the subsequent year (David & Marder, 2018; Marder et al., 2020). This discrepancy is likely due to the fact that the data and models were constructed in slightly different ways. First, the prior studies evaluated the likelihood of a teacher being reassigned to high-stakes subjects given his or her students' prior performance on standardized exams, but this study did not account for the entirety of teachers' teaching assignments. Second, the models in the present study controlled for campus value-added and a teacher's prior teaching assignment, whereas the logistic regression models in the other studies did not. Thus, the models described herein evaluated substantively different aspects of teacher course

As my coauthors and I have argued previously (David & Marder, 2018; Marder et al., 2020), evidence suggests that a teacher's proven track record of either improving or not improving student performance on standardized exams influences the likelihood of that teacher continuing to teach tested subjects, a finding that certainly makes sense given the high-stakes nature of standardized exams in an era of school accountability and that should lead policy makers to consider the unintended consequences of high-stakes accountability measures.

In the present study, teacher ability to improve student test scores—used as a proxy for that teacher quality—is used to explore course assignment in the STEM disciplines more generally. Specifically, a teacher's value-added score is used to predict teacher reassignment from all STEM courses that he or she teaches (not just the high-stakes courses that can be used to compute a value-added score). In this case, a teacher's prior year sector employment, certification, and STEM course assignment have stronger relationships with that teacher's probability of being assigned to different kinds of STEM courses in the subsequent year. The relationships between a teacher's certification, sector employment, and prior year course assignment discussed earlier in this section thus appear to persist, even after controlling for teacher and campus quality.

Chapter 4: Estimating the Joint Causal Effect of Teacher Preparation Pathway and Charter Schools upon Student Outcomes in STEM Disciplines

INTRODUCTION

Charter schools, alternative teacher preparation programs, and other market-based education reforms have become staples of the current educational landscape in the United States. National concern over the quality of the teacher workforce and the quality of the public education system in the United States writ large—particularly in mathematics and science—dates back to the Sputnik era when U.S. students' poor performance in the STEM (science, technology, engineering, and mathematics) disciplines was seen as a threat to the country's military and technological superiority (Lutz & Hutton, 1989; Rudolph, 2002). Similar concerns over the quality of the United States public education system were echoed in 1983's *A Nation at Risk*, which portrayed the United States public education system as the chief reason for a "rising tide of mediocrity" threatening United States' global economic competitiveness (National Commission on Excellence in Education, 1983). In particular, *A Nation at Risk* highlighted both that United States students were underprepared in STEM disciplines when compared to other nations and that educational outcomes differed greatly by students' ethnicity and socioeconomic status. Since *A Nation at Risk*, several federal policy initiatives have cited these issues to justify financial incentives for individual states to promote the expansion of charter schools and alternative teacher preparation programs, under the assumption that these market-based reforms will promote innovation within the public education system (America 2000, 1991; Recovery Act, 2009; Goals 2000, 1994; No Child Left Behind, 2002).

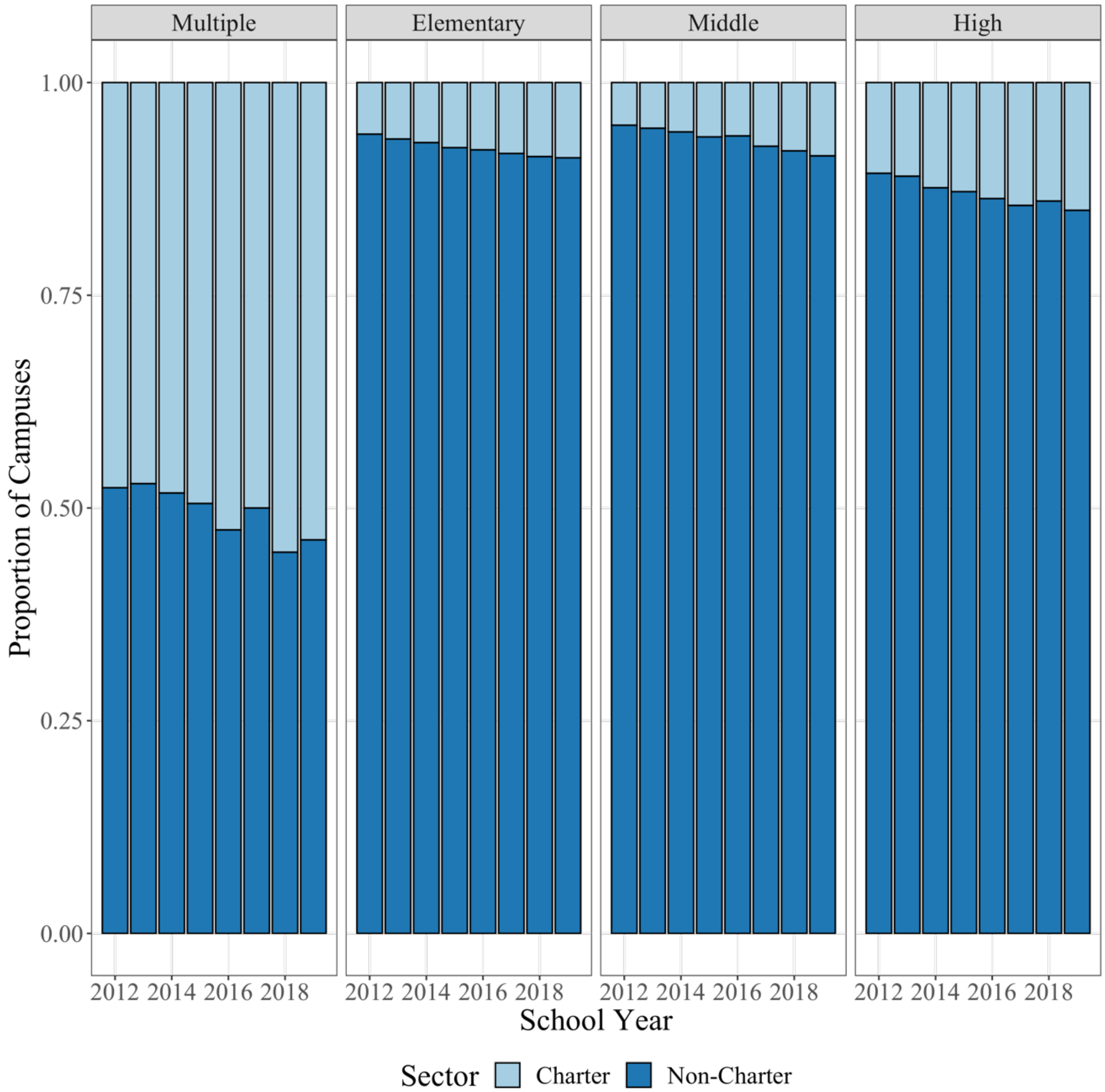

Figure 16. Proportion of charter and non-charter schools in Texas by grade level served.

Charter schools and alternative teacher certifications have experienced rapid growth in the United States (Hanushek et al., 2007; NAPCS, 2018; Suell & Piotrowski, 2007). Such growth is also evident in Texas, as displayed in Figure 16 and Figure 17, which show the proportions of Texas charter and non-charter schools and the proportions of the students enrolling in them by grade level, respectively. As charter schools and alternative teacher preparation programs continue to expand, it is important to evaluate the effects of these education reforms upon student outcomes with particular attention given toward whether or not these reforms have alleviated the concerns they were purportedly designed to address.

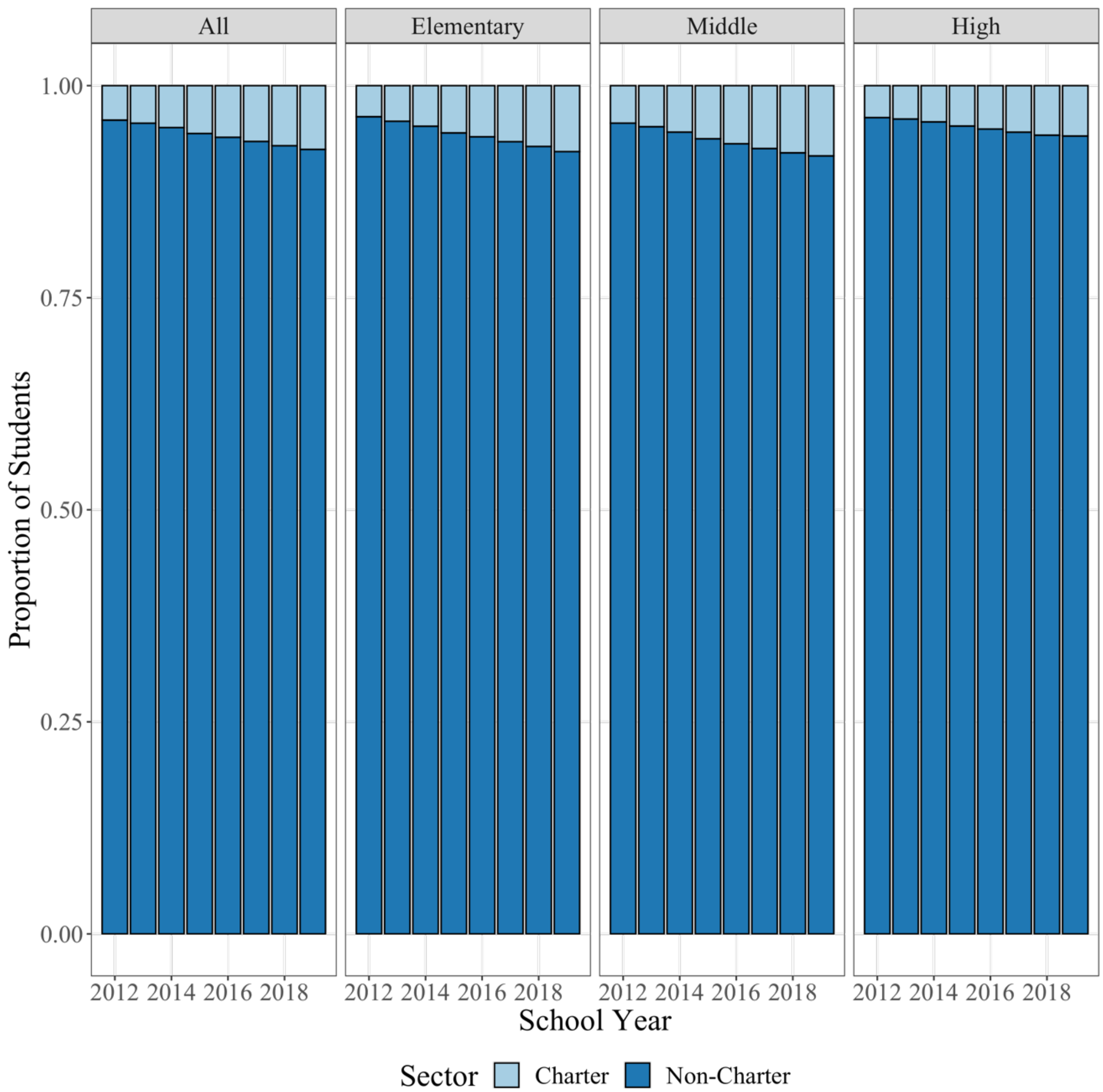

Figure 17. Proportion of Texas students in charter and non-charter schools by grade level.

A wealth of research literature has explored differences in student outcomes between charter and non-charter public schools in addition to differences in student outcomes between traditionally and alternatively certified teachers. There is little consensus within this research as to whether or not charter schools and alternative teacher preparation programs have improved student outcomes. Some research on the effects of charter schools upon student test scores suggests their impact is contextual, varying according to the student demographics served within schools and according to the urbanicity of schools (M. A. Clark et al., 2015). For example, charter schools serving socioeconomically disadvantaged students were found to increase student performance on standardized exams, but this effect was not detected in charter schools serving more advantaged students.

The environmental characteristics of effective and ineffective charter schools identified by Clark et al. (2015) may be confounded with other school-specific variables, such as the design, pedagogies, and curricula employed within certain charter schools. Rather than environmental variables, research using data from Texas suggests that “no excuses” charter schools—schools with longer school days, rigorous test-preparation, and high behavioral standards—improve student test scores and college enrollment, but do not improve labor market outcomes (Dobbie & Fryer, 2016). Moreover, such “no excuses” charter schools more often serve socioeconomically disadvantaged and ethnic minority students in urban settings.

Extant research comparing alternatively and traditionally certified teachers is mixed. Some work suggests there are no statistically significant differences in teacher quality or upon student outcome by teacher preparation pathway (Harris & Sass, 2011; Suell & Piotrowski, 2007), and that differences in teacher effectiveness vary more within preparation programs than between them (Kane et al., 2008). By contrast, in a study using student performance on algebra 1 and biology standardized exams to evaluate alternatively and traditionally certified STEM teachers in Texas, Marder et al. (2020) find that algebra 1 students in classes taught by traditionally certified teachers experienced higher increases in their standardized exam scores than their peers in classes taught by alternatively certified teachers. Although biology students in traditionally certified teachers' classrooms generally scored higher on standardized exams than peers in alternatively certified teachers' classrooms, these differences were not often statistically significant.

Most research evaluating the effects of market-based education reforms has explored charter schools and teacher preparation pathways separately; however, some scholars suggest that together these education reforms form an educational structure that is "parallel" to the traditional public education system (Kretchmar et al., 2014; Mungal, 2016; Stitzlein & West, 2014). In this "parallel" education structure, teachers certified through alternative preparation programs are overrepresented in charter schools, in part due to ideological similarities in their educational paradigms. Standard certified teachers, by contrast, are more likely to teach in non-charter public schools than in charter schools. Despite these findings, research has not systematically explored the effects of this "parallel" system upon student outcomes, nor has research explored the degree to which differences in the effects of teacher preparation program may depend upon the sector in which these teachers are employed.

In addition to investigating teacher preparation and school sector separately, a majority of the research on the effects of market-based reforms has not focused upon student outcomes in STEM—disciplines that have been designated "high-needs" for a long time—but rather upon student learning gains in mathematics and reading, the academic subjects most commonly used to evaluate schools' adequate yearly progress as mandated under *No Child Left Behind* legislation (No Child Left Behind, 2002). Although mathematics is one of the STEM disciplines, that it is the only routinely tested subjects leads to concern over whether the other disciplines are given proper academic attention. This work seeks to expand upon existing literature by exploring the degree to which the intersection of charter schools and alternative teacher preparation pathways has affected student learning outcomes and engagement within the STEM disciplines. Specifically, this project draws upon student- and teacher-level administrative educational data from Texas to address the following research question: *Do the effects of teacher preparation pathway (alternative or traditional certification) upon student outcomes in mathematics and science differ by school sector (e.g., charter and non-charter public schools)?*

I employ two causal methods to estimate the joint effect of teacher preparation pathway and school sector upon student performance on standardized exams in STEM subjects. The first analysis consists of a hybrid crossover and nonrandomized block research design in which students switching sectors in their transition from 8^{th} and 9^{th} grade are blocked by campus and county. For the second analysis, I build a Directed Acyclic Graph (DAG) to articulate the causal mechanisms responsible for the joint effects of teacher preparation pathway and school sector upon student performance. From this DAG, I build a regression model to estimate the joint causal effect of school sector and teacher preparation pathway upon student outcomes in STEM.

Research has shown that the variation within teacher certification pathways (alternative and traditional certification) and school sector (charter or non-charter) is greater than the variation between these market-based reforms and aspects of the "traditional" education system. If, however, teachers from specific preparation programs are recruited by schools that are ideologically similar to these preparation programs and employ pedagogical methods and curricula that align with the pedagogies and curricula taught within certain teacher preparation pathways, then it is presumable that teachers will be more effective in these settings than teachers prepared in other programs. This work seeks to identify whether or not such an effect upon student outcomes in STEM exists. In addition, by constructing two causal models, this work seeks to compare different causal methodologies, evaluating the benefits and limitations of each.

LITERATURE REVIEW

In the literature review, I first discuss existing research investigating the effects of charter schools and teacher preparation pathways upon student outcomes. Following a review of this research, I discuss various perspectives on causal inference using observational data.

Research on the Effects of School Sector and Teacher Preparation Pathway

Substantial bodies of research have investigated the effects of charter and non-charter public schools upon student outcomes in addition to the effects of alternative and traditional teacher preparation pathways upon student outcomes. In general, these literature bases have been distinct from one another. Recent qualitative research, however, has begun to characterize commonalities between charter schools and alternative certification programs, as both are neoliberal, market-based reforms seeking to promote innovation and improvement in the public education system by introducing competition into the public education sector. In particular, pedagogies espoused in highly selective alternative teacher preparation programs, specifically Teach For America (TFA), align with the educational models employed in “no excuses” charter schools, and many charter school networks have been started by TFA alumni (Kretchmar et al., 2014; Lefebvre & Thomas, 2017; Stitzlein & West, 2014). Given the nature of the existing literature exploring the independent effects of school sector and teacher preparation pathway upon student outcomes, in addition to the emerging literature base seeking to characterize the commonalities between these market-based reforms, this literature review discusses results from quantitative studies seeking to identify the causal effects of charter schools and alternative certification programs upon student outcomes in addition to qualitative studies describing the ways in which these two market-based reforms have become aligned with one another.

Literature exploring differences in student achievement between charter and non-charter public schools suggests the impact of charter schools upon student outcomes (most often as measured using standardized exam scores) is contextual (Gleason et al., 2010; Zimmer et al., 2012). In a study looking at student achievement in charter and non-charter schools across seven states, Zimmer et al. (2012) concluded there was little or no difference by sector, as charter schools in some states tended to increase students' test scores in math and reading, while charter schools in other states decreased students' standardized test scores. In a different study, Gleason et al. (2010) took advantage of the lottery-based admissions system at 33 charter middle schools across 13 states to compare student outcomes. On average, Gleason et al. (2010) found no differences in student achievement in math or reading between charter and non-charter public schools; however, differences in student achievement were found when disaggregating schools by student populations. Specifically, charter schools serving underperforming, low-income students yielded positive student outcomes in mathematics, whereas charter schools serving high-performing, high-income students yielded negative student outcomes in mathematics and reading. In a separate article using data from the same study, Clark et al. (2015) describe that charter schools in urban settings improve student mathematics scores while charter schools in non-urban settings do not.

The contextual differences reported by Gleason et al. (2010) and Clark et al. (2015) are more plausibly attributable to the design and mission of specific charter schools.

Dobbie and Fryer (2016) examined a variety of outcomes—student test score gains, college enrollment, and early labor market outcomes—of charter school graduates from Texas. Specifically, "no excuses" charter schools—schools with longer school days, rigorous test preparation, and high behavioral standards—were found to increase student test score gains and college enrollment but have little noticeable impact upon graduates' future earnings. Other charter schools, by contrast, were associated with decreases in student test scores, college enrollment, and future earnings. Sass et al. (2016), however, provide contrasting evidence from Florida that shows "no excuses" charter schools are associated with increased earnings among graduates.

Additional evidence for the importance of a charter school's educational model on student achievement comes from Curto and Fryer (2014) who studied student math and reading achievement at SEED, an urban, boarding, college-preparatory charter school in Washington, D.C. When comparing students randomly selected for attendance through the lottery-based admissions system to students not selected for attendance, Curto and Fryer (2014) report students attending SEED increased their math and reading scores. While SEED's boarding component is a unique feature of this school, another plausible reason for SEED's effectiveness in improving math and reading scores may be its "no excuses" educational paradigm (Curto & Fryer, 2014), an instructional and behavioral model that scholars have argued is responsible for the success of "highly-effective" charter schools elsewhere (Cheng et al., 2017; Dobbie & Fryer, 2011, 2013, 2015).

The effects of teacher preparation pathway on student outcomes are similarly mixed. Suell and Piotrowski (2007) describe literature comparing alternatively and traditionally certified teachers that concluded "there were no differences in teaching behavior, student output, or perception of competence" by teacher preparation pathway. In studying teacher training, teacher quality, and student outcomes, Harris and Sass (2011) report that experience, particularly in the first five years of a teacher's career, is associated with increases in student achievement, but that teachers' pre-service training and college entrance exam scores are not related to student achievement. von Hippel et al. (2016) attempt to rank teacher preparation programs using value-added modeling, but report that the teacher preparation estimates are too noisy to effectively distinguish between teacher preparation programs. In a separate work analyzing data from six states, von Hippel and Bellows (2018) similarly show that it is difficult to detect the effects of different teacher preparation programs and describe that most teacher preparation programs do not result in statistically significant differences in student outcomes as measured by standardized test scores. Counter evidence from Texas suggests that traditionally certified STEM teachers are more effective than their alternatively certified colleagues at producing test score gains on standardized assessments (Marder et al., 2020). This study found that students in classrooms with traditionally certified teachers experienced statistically significantly higher gains in mathematics than their peers in classrooms taught by alternatively certified teachers. Although differences in biology generally favored students in classrooms with traditionally prepared teachers, these differences were smaller and not statistically significant.

While noisy value-added estimates make it difficult to rank the effectiveness of individual teacher preparation programs, as von Hippel et al. (2016) show, the results put forth by Marder et al. (2020) indicate there are meaningful differences between teacher preparation pathways more generally. In addition, it is also important to consider other notable differences between alternatively and traditionally certified teachers. As compared to alternatively certified teachers, traditionally certified teachers are more likely to stay in the teaching profession for longer periods of time (Darling-Hammond, 2000; Ludlow, 2013). Alternatively certified teachers, however, are more likely to serve in socioeconomically impoverished settings and are more likely than traditionally certified teachers to come from ethnic minority populations (Ludlow, 2013).

Taken together, existing research on charter schools and alternative teacher preparation pathways indicate that it is often difficult to differentiate the effects of these reforms from the effects of the traditional public system (consisting of traditional teacher preparation pathways and non-charter public schools). Some scholars argue, however, that the neoliberal ideals of market-based reforms have created a parallel system within public education. Mungal (2016) describes that in New York City, TFA and the Relay Graduate School prepare pre-service teachers for employment primarily in charter schools, whereas teachers prepared in standard, university-based teacher preparation programs typically teach in New York City Public Schools. Lefebvre and Thomas (2017) contend that alternatively certified teachers recruited through TFA perceive that they perform better in charter schools where the educational paradigm is concordant with their training in TFA, which may explain why TFA and other alternatively certified teachers are more likely to teach in charter schools than are teachers certified through standard preparation routes. Stitzlein and West (2014) also provide evidence that suggests certain teacher preparation programs—specifically Relay and Match—promote ideals and pedagogies that are aligned with ideals and pedagogies used in charter schools. Research investigating how teachers navigate labor markets has found evidence to suggest that while teachers generally prefer working in non-charter public schools because these schools offer higher salaries and greater stability, some teachers prefer working in charter schools because of ideological similarities (Cannata, 2011; Jabbar et al., 2019).

Despite findings suggesting that there are no average effects on student outcomes by school sector or by teacher preparation pathway, that scholarship suggests these reforms have aligned to form new structures within public education necessitates that research investigate the joint effects of charter school and teacher preparation pathway upon student outcomes. Moreover, a great deal of the studies exploring the effects of charter schools and teacher preparation pathways on student achievement use math and reading scores, but do not research student outcomes specifically in STEM as a whole. Given that federal policies have foregrounded the inadequate preparation of students in STEM in the United States when justifying financial incentives for the expansion of market-based educational reforms, it is important to evaluate whether or not the growth of market-based reforms with the United States public education system have impacted student access to and engagement in STEM disciplines.

Causal Analysis

Understanding the causal underpinnings of the natural and social worlds lies at the heart of many research endeavors. The natural sciences—biology, chemistry, and physics—have long established histories of using experimentation to better understand the causal mechanisms responsible for biological and physical phenomena. Research in the social sciences similarly aims to uncover the relationships between social agents to elucidate the causal mechanisms underlying social phenomena. In education research and social science research writ large, there has been ample (and lively!) debate surrounding the nature of causality and the methods most appropriate for evaluating and identifying cause-and-effect relationships (Campbell & Stanley, 1966; Deaton & Cartwright, 2018; Pearl, 2018; Rubin, 1974).

Examining cause-and-effect has been identified as an important goal for researchers and policy-makers in the current era of educational reform in which charter schools and other market-based reforms have taken center stage. Specifically, the *No Child Left Behind Act*, enacted into legislation in 2002, provided funding to educational entities, non-profit organizations, and public-private partnerships with the goal of encouraging the development of innovative educational strategies to help students achieve state learning standards. To evaluate the efficacy of these projects, the *No Child Left Behind Act* recommends "using rigorous methodological designs and techniques, including control groups and random assignment, to the extent feasible, to produce reliable evidence of [the] effectiveness" of the educational projects funded (No Child Left Behind, 2002, p. 1597). In addition, 2009's *American Recovery and Reinvestment Act* similarly provided funding geared specifically for innovation and improvement with the stipulation:

> That a portion of these funds…also be used for a rigorous national evaluation by the Institute of Education Sciences, utilizing randomized controlled methodology to the extend feasible, that assesses the impact of performance-based teacher and principal compensation systems supported by the funds provided in this Act on teacher and principal recruitment and retention in high-need schools and subjects. (Recovery Act, 2009, p. 182)

Not only has recent legislation been favorable to reform efforts that are designed to spur innovation in the public education system, but the need to evaluate these programs in such a way to better understand the causal results of these innovations is a key component included within this legislation.

Understanding casual mechanisms in education is not limited to educational policy, however. The advent of data-driven instruction (following the enactment of *No Child Left Behind* which established high-stakes accountability measures for public schools) further exemplifies the broad importance of causal relationships and causal understanding to educational practice. Data-driven instruction is a practice in which teachers routinely collect and analyze standardized-testing data on their students in order to alter and improve their instruction (Kronholz, 2012).[7] In data-driven instruction, data analysis is portrayed as

[7] In discussing data-driven instruction, Kronholz (2012) describes the work of Achievement Network (ANet), a non-profit organization that partners with schools to administer mock standardized exams regularly throughout the academic year and then supports teachers in using this data to analyze and adjust

a necessary measure for teachers to evaluate the impacts of their instruction and adjust their pedagogical decision-making and curricula to better support student learning. Campbell and Stanley (1966) similarly describe the role of causality in educational practitioners' decision making processes through the hypothetical example of Principal John Doe, faced with a decision to purchase a the new version of a textbook or to use an old version. Rather than employing an experimental design to find the best textbook, Principal Doe will likely weigh the benefits and costs of both options in coming to a decision. Although Campbell and Stanley (1966) use the example of Principal Doe to illustrate the ways in which the evolution of knowledge within education has typically not followed a rigorous experimental process, their example nevertheless illustrates that causal reasoning enters education not only at the policy level, but also at the practitioner level.

Pearl (2009a) contends that although many research questions in the social sciences are causal, social science researchers have not traditionally employed statistical methods capable of accounting for the causal nature of their questions, and instead rely upon statistical inference. Whereas statistical inference leverages properties of data distributions in order to describe associations between variables of interest, addressing causal questions necessitates that researchers have "some knowledge of the data-generating process" (Pearl, 2009a, p. 97). In conceptualizing and theorizing causality in the social sciences, researchers

their instruction. The school at which I taught physics and physical science prior to enrolling in graduate school, was an ANet school. Tests were administered three times throughout each academic year, and soon after each administration, an ANet team member would host an in-service training dedicated to analyzing the data and identifying areas in which students were underperforming. Students were then placed into "targeted-instruction" classes tailored specifically toward additional practice with the particular content that each student most often answered incorrectly on the practice exam. I cannot say that I was particularly fond of the experience, nor did I find it useful. Our analysis of data was not at all rigorous, and other than "targeted-instruction" classes, I did not see that analyzing data resulted in changes to teachers' instructional practices. In addition, the only subjects tested during these ANet sessions were reading and mathematics, the standardized tests upon which public schools were evaluated. As such, the "data-driven" enterprise seemed mostly an opportunity for students to regularly practice taking standardized exams and for teachers to subsequently drill students on the content they most commonly missed on these exams.

have proposed different methods and adopted various philosophies. Prior to estimating the joint causal effect of teacher preparation pathway and school sector upon student outcomes in STEM, as I intend to do with this paper, it is important to consider the various philosophical stances that have sustained different methodological traditions within the causal inference literature.

In the sections that follow, I first provide an overview of the literature on causal methods and causal inference in the social sciences. Then I evaluate the merits of these philosophies in the context of the present research project and describe how I will use these methods to address the research question articulated in the introductory section.

Formulations of Causal Inference

Campbell and Stanley (1966) published a guide for educational researchers describing the merits and drawbacks of pre-experimental, experimental, and quasi-experimental research designs. In their work, Campbell and Stanley clearly favor experimental research designs over pre- and quasi-experimental designs, claiming that the researcher has greater control over the manner in which data are collected, measured, and analyzed. These authors organize their critique of sixteen research designs according to eight criteria (history, maturation, testing, instrumentation, regression, mortality, selection, and the intersection of these factors) to evaluate the internal validity of these research designs and four criteria (the intersection of testing and the treatment, the intersection of selection and the treatment, reactive arrangements, and the interference between multiple treatments) to evaluate the external validity of these designs (Campbell & Stanley, 1966).

In true experimental designs, of which Campbell and Stanley (1966) describe three, the effect of a treatment is measured after randomly assigning study participants to one of two (or more, depending upon the specific research design) groups. In the most basic experimental design, which includes only two groups, the "treatment" group receives an experimental treatment and the "control" group does not. Differences in a measured outcome between the treatment and control groups can then be causally attributed to the experimental treatment. According to Campbell and Stanley (1966), experimental designs are the best suited research designs for ensuring the internal validity of a study, meaning that the effects detected are due to the treatment and not to other causes characteristic of the treatment group. Randomly assigning study participants to treatment and control groups serves as "the all-purpose procedure for achieving pretreatment equality of groups, within known statistical limits" (Campbell & Stanley, 1966, p. 6). Experimental designs are preferred on account of the purported equivalence between the groups created, whereas quasi-experimental methods make "extant intact comparison groups of unassured equivalence" (Campbell & Stanley, 1966, p. 13).

Deaton and Cartwright (2018) provide a general equation (given by Equation 10) to calculate the effect of a treatment, T_i, on an outcome of interest, Y_i, for individual *i* (p. 3):

$$Y_i = \beta_i T_i + \sum_{j=1}^{J} \gamma_j x_{ij} \tag{10}$$

The difference in the outcome of interest between the treatment and control groups is given by Equation 11 (Deaton & Cartwright, 2018, p. 4):

$$\bar{Y}_t - \bar{Y}_c = \bar{\beta}_t + \sum_{j=1}^{J} \gamma_j \left(x_{tij} - x_{cij} \right) \tag{11}$$

To estimate the average treatment effect (ATE; the beta term in Equation 11), the second term on the right-hand side (the sum of the covariates, x_{ij} for the treatment and control groups) should be equal to zero, or at least close to zero.

Randomization within the experimental designs described by Campbell and Stanley (1966) is theorized as one way minimize the differences in the x_{ij} variables between treatment and control groups that may also cause the observed effect. The utility of randomization in experimental design can be traced to work by Fisher (1935). Randomization is put forth as a process by which individual characteristics that may also affect the experimental outcome are distributed evenly among the treatment and control groups so that the researcher can isolate the effect of the treatment. In the limit of many experimental trials:

> [T]he over-representation of the unbalanced causes will sometimes be in the treatments and sometimes in the controls. The imbalance will vary over replications of the trial, and although we cannot see this from our single trial, we should be able to capture its effects on our estimate of the ATE from an estimated standard error. (Deaton & Cartwright, 2018, p. 5)

From this estimated standard error, it is possible to find the associated significance; however, Deaton and Cartwright (2018) caution that this does not necessarily yield a correct estimate of the causal effect, a point which will be discussed in greater detail later.

Although Campbell and Stanley (1966) note that randomization of treatment and control groups ensures the pretreatment equality of these groups, they also contend that randomized experimental designs have limited external validity, meaning they cannot be readily generalized to populations not included in the study. Nevertheless, Deaton and Cartwright (2018) note, “The drive to export and generalize RCTs results is at the core of the influential ‘what works’ movement across the medical and social sciences. At its most ambitious, this aims for universal reach” (p. 11). In education, this mentality is evident in legislation promoting market-based reform as a means for spurring innovation (Recovery Act, 2009; No Child Left Behind, 2002), and calls to experimentally verify the efficacy of social policy are evident as early as “Great Society” legislation (Campbell, 1969).

Given the over-reliance on RCTs in the social sciences, Deaton and Cartwright (2018) question its universal applicability, expressing a number of concerns. While randomization can prove useful, particularly when no prior information regarding the causal relationship between variables being investigated is available, using prior information and theory as a basis upon which to build causal analysis is generally superior (Deaton & Cartwright, 2018; Pearl, 2009a, 2018; Rubin, 1974). In addition, Deaton and Cartwright (2018) express other concerns over the use of RCTs to estimate causal effects. Specifically, these authors argue that randomization does not ensure that the treatment and control groups are truly independent of one another, nor does randomization absolutely mitigate all group differences. There may be unobserved causes that are unevenly distributed in the treatment and control groups that affect the estimate of the effect, as will outliers in one or both groups. With respect to the efficacy of randomization, Deaton and Cartwright (2018) "strongly contest the often-expressed idea that the ATE calculated from an RCT is automatically reliable, that randomization automatically controls for unobservables, or worst of all, that the calculated ATE is true" (p.10).

Given these concerns with randomization, Deaton and Cartwright (2018) illustrate the fallibility of generalizing results from RCTs through the following example:

> Bertrand Russell's chicken (Russell, 1912) provides an excellent example of the limitations to simple extrapolation from repeated successful replication. The bird infers, on repeated evidence, that when the farmer comes in the morning, he feeds her. The inference serves her well until Christmas morning, when he wrings her neck and serves her for dinner. Though this chicken did not base her inference on an RCT, had we constructed one for her, we would have obtained the same result that she did. Her problem was not her methodology, but rather that she did not understand the social and economic structure that gave rise to the causal relations that she observed. (p. 11)

Although RCTs and the experimental designs described by Campbell and Stanley (1966) are one way to minimize the difference between the covariates of the treatment and control groups in Equation 11, other methods are also available in cases when randomization is not feasible. Moreover, in contrast to Campbell and Stanley (1966), who advocated for experimental studies with randomized treatment and control groups as the only means to evaluate educational interventions, Rubin (1974) argues, "Even if the position that causal effects of treatments can only be well established from randomized experiments is taken as applying only to the social sciences in which there are currently few well-established causal relationships, its implication—to ignore existing observational data—may be counter-productive" (p. 688). Toward this end, Rubin (1974, 2005) describes a "counterfactual" approach to evaluating causality using observational data.

Rubin's "counterfactual" causal framework contends that although an individual was assigned to a specific group—either treatment or control—it is possible that individual could have instead been assigned to the other group. In practice it is only possible to measure one outcome for any given individual, $Y_i(T)$, for example, it is presumable that another outcome for that individual, $Y_i(C)$, would have been measured had that individual been assigned to the control rather than the treatment group. The counterfactual approach leverages the fact that the difference in the means between two values is equal to the mean of the difference between two values, and therefore Equation 11 is not necessarily limited to use exclusively with RCTs (Deaton & Cartwright, 2018; Holland, 1998; Rubin, 1974, 2005; Winship & Morgan, 1999). Through Rubin's formulation of causality, it is possible to ascertain causality using observational (nonrandomized) data by finding the average treatment value from the average control value, $\bar{Y}_t - \bar{Y}_c$, using data in which individuals were not necessarily assigned to treatment randomly.

Although Rubin provides a framework with which to infer causality through observational data, it is important to give attention to the manner in which observations are assigned to the treatment and control groups so as to minimize bias (Winship & Morgan, 1999). One such method when inferring causality within observational data involves matching treatment observations with controls. In matching, individuals in an observational data set who received a given intervention or treatment of interest are paired with another individual (or individuals) who did not receive that intervention (Deaton & Cartwright, 2018; Rosenbaum & Rubin, 1983; Rubin, 1974). These individuals are paired such that their x_{ij} variables are closely aligned, thereby minimizing the summation term in Equation 11. A variety of methods exist for matching individual observations in observational data, including propensity score matching in which individuals are paired such that their average attributes are equal (Rosenbaum & Rubin, 1983) and the creation of a synthetic control group which is constructed splicing and fusing attributes from a number of different observational units to form a control unit that closely resembles the treatment unit in all but receiving the treatment (Abadie et al., 2010)

In addition to the causal methods introduced thus far, Pearl (Bareinboim & Pearl, 2016; Pearl, 2009a, 2009b) has written extensively on the subject of causality using observational data and has developed his own framework and formulation for causal inference. Pearl (2009b) writes:

> We view the task of causal discovery as an induction game that scientists play against Nature. Nature possesses stable causal mechanisms that, on a detailed level of descriptions, are deterministic functional relationships between variables, some of which are unobservable. These mechanisms are organized in the form of an acyclic structure, which the scientists attempts to identify from the available observations. (p. 43)

To uncover the causal rules of nature, Pearl's formulation of causality employs structural equation modeling (SEM) and Bayesian statistics (Pearl, 2009b, 2009a). Through the use of a directed acyclic graph (DAG), in which the researcher draws arrows between variables to illustrate the causal structure of the data being analyzed, the researcher is able to both articulate a conception of causality to be tested and use the DAG to uncover the joint probability function that mathematically articulates the causal effect of the social phenomena being investigated.

Adopting a Causal Framework

As Pearl (2018) contends, “considering the practical difficulties of conducting an ideal RCT, observational studies have a definite advantage: they interrogate populations at their natural habitats, not in artificial environments choreographed by experimental protocols.” Similar positions have also been taken among researchers investigating student cognition in science. For example, Sherin (2000) argues for a “genetic” account of students’ representational capacities over other psychological studies that seek to probe students’ cognitive mechanisms within highly controlled environments. In framing an investigation into students’ broader capacities, situated in authentic contexts, a different view of students’ capabilities is gained, one that is not contrived to fit within the “laboratory” setting, thereby isolating phenomena that are inextricably linked to the contexts in which cognition occurs.

While there are certainly circumstances in which the highly controlled experimental studies are beneficial, such as when little prior information about an intervention or treatment is known, Pearl’s (2018) contention that there is value in analyzing observational data that “interrogate populations at their natural habitats” is particularly apt for investigating school choice. On the one hand, isolating the effect of an intervention through the “counterfactual” model proposed by Rubin (1974, 2005) is instructive and fairly intuitive: by controlling for all variables (either through randomization or matching), a convincing argument can be made for the causal effect of a treatment variable upon an outcome of interest. The counterfactual method, however, does not have the robustness of Pearl’s formulation, in which the entire causal structure, including unknown variables, is considered when determining the joint probability function governing causal interaction (2009b, 2009a).

Although in theory, randomization guarantees the equivalence of the treatment and control groups in the limit of infinite trials, Deaton and Cartwright (2018) caution that in fewer trials, the estimate of the causal effect is subject to misinterpretation should the treatment and control groups have unevenly distributed confounding variables or should one of these groups have significant outliers in the measured effect. In addition, the use of matching to ascertain a causal effect presumes that all relevant causal variables are known, when in fact this is likely not the case in social sciences. As Rubin (1974) articulates, comparatively few causal relationships are known in the social sciences and in education research. Toward this end, Pearl's (2009b, 2009a) formulation of causality is based upon the premise that Nature has hidden the causal structure from the researcher as a probability distribution. By perturbing the system, the researcher can infer the causal mechanisms encoded in this joint probability distribution. This formulation allows for researchers to infer causal relationships by investigating probabilistic structure in observational data sets.

In the present analysis, I adopt conceptions of causality that allow for cause-and-effect to be ascertained from nonrandomized, observational data. The charter school movement has been positioned as an educational reform that will induce innovation and beget improvements in student outcomes, and legislation enacted that supports charter schools and other market-based reforms encourages the use of RCTs to determine the causal effects of these interventions. What ample research shows, including studies that take advantage of natural experiments like the lottery system that determines charter school admissions, however, is that charter school impacts are by no means universal (M. A. Clark et al., 2015; Dobbie & Fryer, 2016; Gleason et al., 2010; Tuttle et al., 2012). Certain "no excuses" schools are shown to increase student performance on standardized exams and in college enrollment, but these findings neglect to consider the mechanisms within these specific charter schools that are causally responsible for the observed outcomes. Moreover, there are concerns that these "no excuses" charter schools are not engaging in culturally relevant pedagogy, but instead infusing their educational programs with middle-class values in such a way that neglects diverse students' cultural traditions and ways of knowing (McDermott & Nygreen, 2013). By adopting a causal framework in which it is possible to evaluate the effects of interventions within observational data and by articulating a theory that explains the causal mechanisms within the social system, it is possible to account for a variety of factors that can be ignored when pursuing RCTs.

DATA AND SAMPLE

To estimate causal effects of charter schools and alternative certification upon student outcomes, this study analyzed data from Texas. Data were made available by the Texas Education Research Center (ERC), which collects and maintains student-, teacher-, campus-, and district-level data for all public education institutions in Texas. In particular, the Texas ERC data repository contains student-level demographic, attendance, mobility, and performance data from the Texas Education Agency (TEA); teacher-level demographic and certification data from the State Board for Educator Certification (SBEC); school- and district-level administrative and accountability data from TEA; and individual-level college admissions, enrollment, and performance data from the Texas Higher Education Coordinating Board (THEBC). Through unique identifiers, students can be matched to the schools and courses in which they were enrolled for a given year. Similarly, teachers can be matched to the schools at which they were employed and the specific courses they taught for a given year. Prior to the 2011-2012 school year, students and teachers could be matched through the classes with which both were associated, but matching was not reliable because term (e.g., spring or fall semester) data was not included. Starting in the 2011-2012 school year, ERC data allowed for students and teachers to be matched through mutual membership in a given course during a given term, which has allowed for greater accuracy in teacher-student matching. Given that student-teacher matching became possible in the 2011-2012 school year, data analyzed in this study draw from the 2011-2012 to the 2018-2019 school years.

Although the population of Texas public school students, teachers, and administrators are represented in the data maintained by the Texas ERC, this study uses a smaller subset of this population. While the number of charter schools has grown considerably in Texas since they first emerged in the mid-1990's (see Figure 16 and Figure 17), an overwhelming majority of the schools across Texas are non-charter schools, and charter schools are concentrated in comparatively few areas (e.g., Austin, Dallas, Houston, San Antonio, the Rio Grande Valley, and El Paso, as shown in Figure 18). Each of these geographical areas are either urban, populated with a large proportion of ethnic minority and socioeconomically disadvantaged populations, or both. Since the goal of this study is to estimate the joint causal effect of alternative certification and charter schools upon student outcomes in STEM, it is important to limit the data set to regions in which students and teachers have access to both charter schools and non-charter schools. The maps in Figure 18 show the number of charter and non-charter schools in Texas and indicate which Texas counties are included in the present study. To be included in the analysis, a county must have had more than one charter school and more than one non-charter school in operating during a given year.

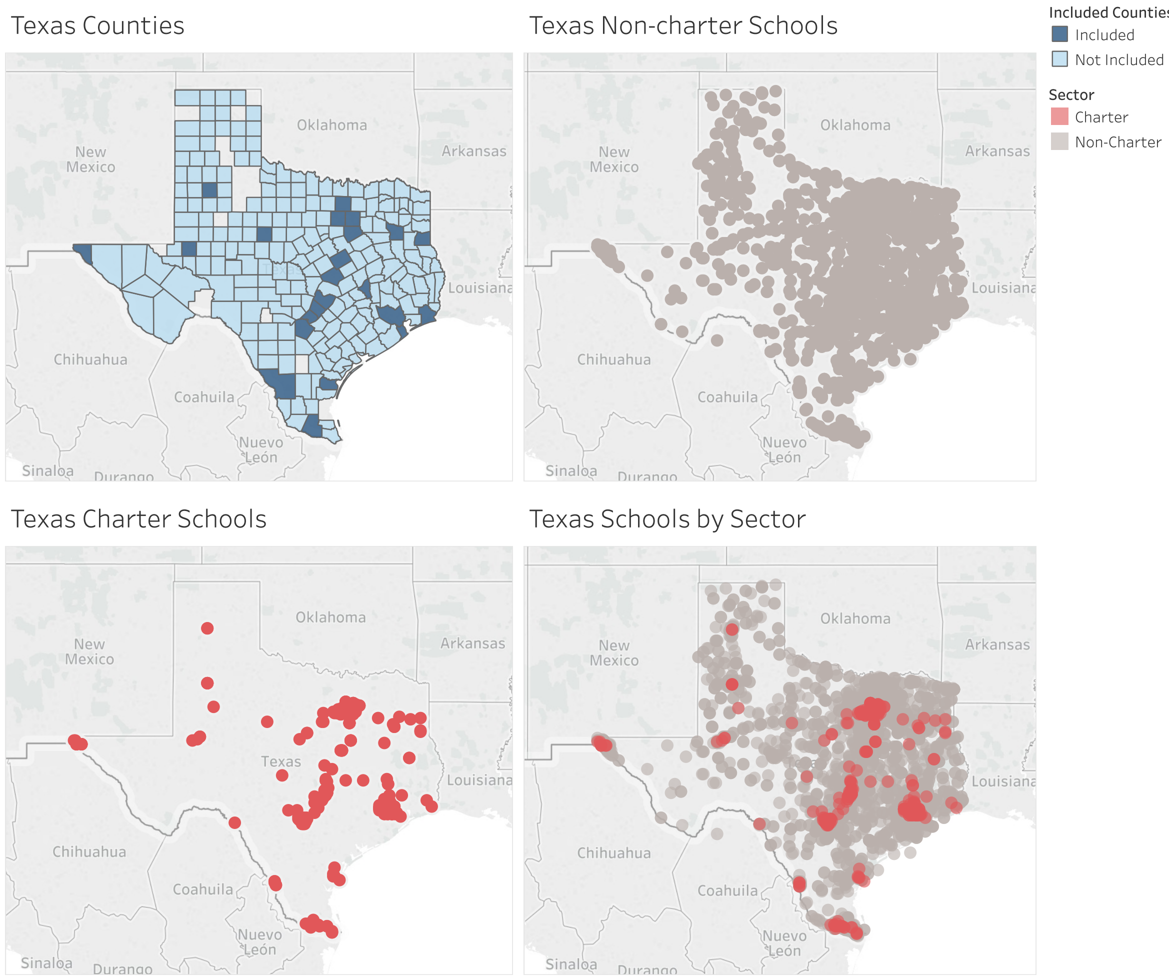

Figure 18. Top left: Map of Texas counties included and non-included in this study. Top right and bottom: Maps showing charter and non-charter middle and high schools in Texas.

The average demographic characteristics of students in charter and non-charter schools within each of the counties included in this study are provided in Figure 19 and Figure 20. Figure 19 gives the average racial composition of students in charter and non-charter schools by Texas county for all years included in the study, and Figure 20 gives the corresponding plots for special student populations (e.g., economic disadvantage, SPED).

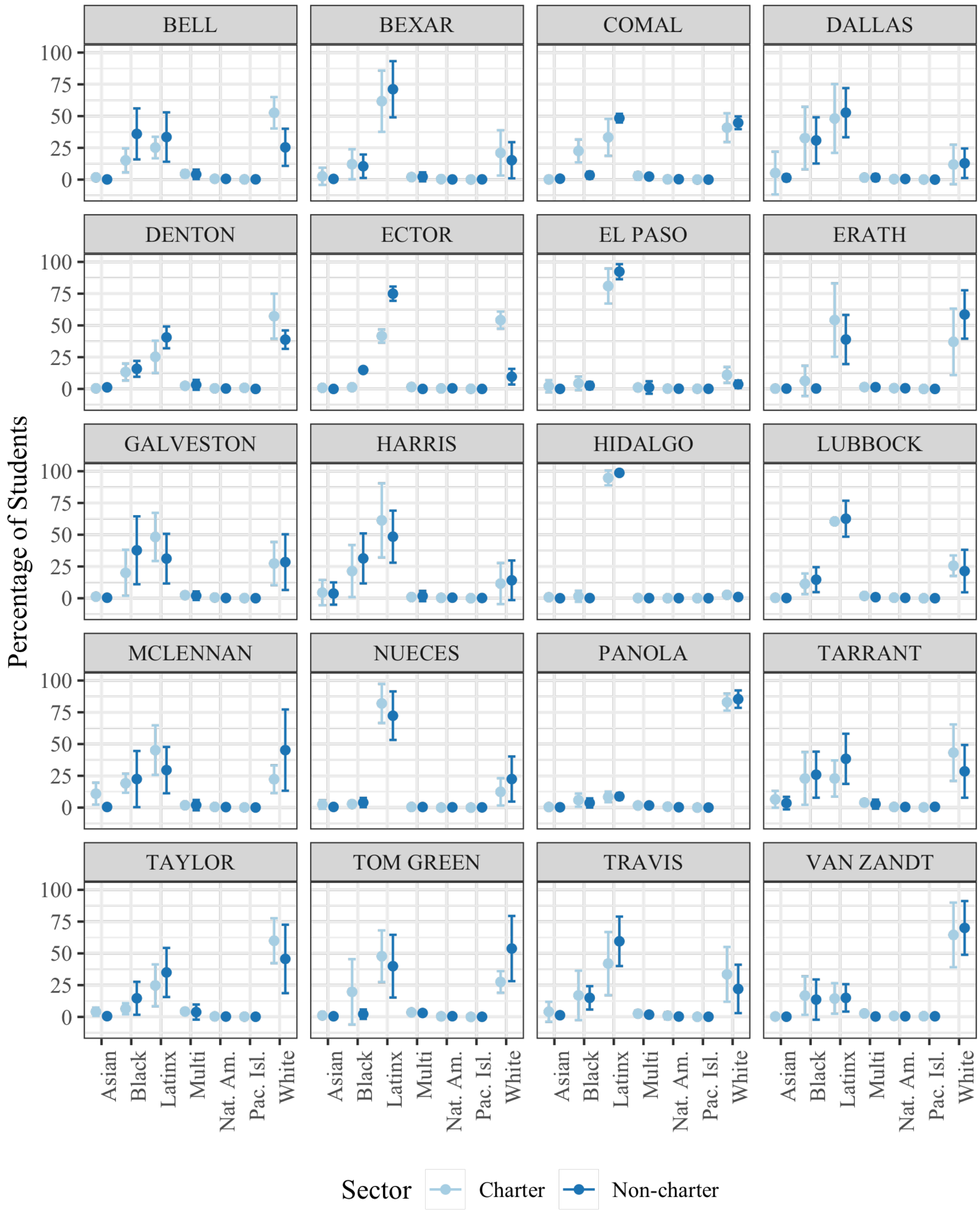

Figure 19. Average racial composition of students enrolled in charter and non-charter schools by Texas county for all years included in this study.

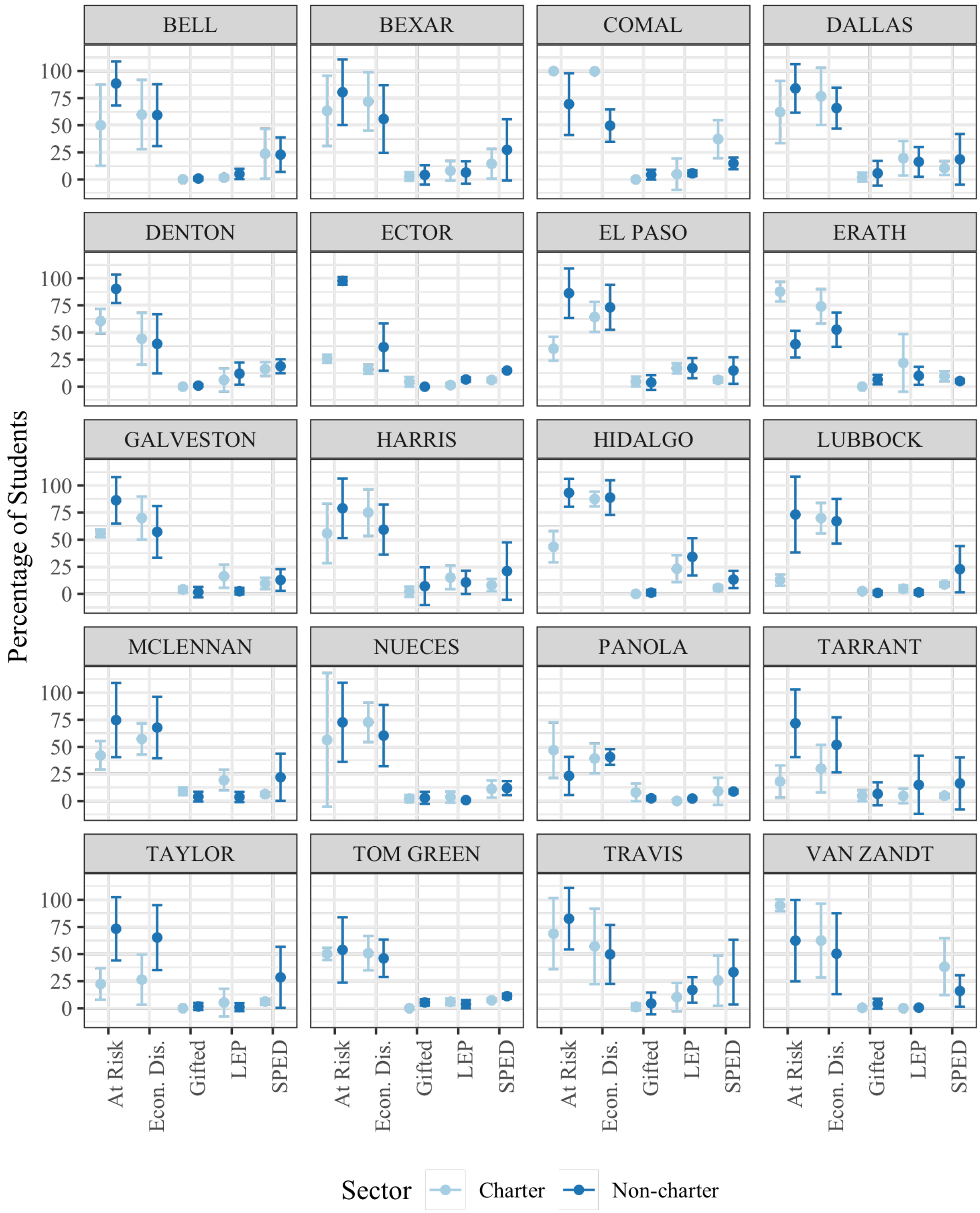

Figure 20. Average special population composition students enrolled in charter and non-charter schools by Texas county for all years included in the study.

As illustrated in Figure 19, the demographic composition by ethnicity of charter and non-charter schools are, for the most part, comparable within the counties included in this study. Notable differences between the ethnic characteristics of charter and non-charter schools include the different percentages of white students attending charter and non-charter schools in McLennan and Tarrant counties in addition to the different percentages of Latinx students by sector in Bell, Harris, and Hays counties.

With respect to special populations served in Texas charter and non-charter schools, Figure 20 indicates that charter schools are more likely than non-charter schools to serve students labeled "at-risk" for dropping out of school and students eligible for free and reduced lunch (FRL), particularly in Bell, Bexar, Comal, Hays and Webb counties. By contrast, charter schools in Tarrant and Taylor counties are less likely than non-charter schools to serve students labeled "at risk" or eligible for FRL. Finally, in Comal and Hays counties, charter schools serve a higher percentage of special education (SPED) students than non-charter schools. Aside from these differences, the compositions of students by special population in charter and non-charter schools included in this study are relatively comparable.

The percentage of teachers from alternative and traditional certification programs in charter and non-charter schools and the ethnic and gender composition of charter and non-charter public school teachers analyzed in this study by pathway are displayed in Figure 21. Although both charter and non-charter schools have higher percentages of teachers from alternative preparation programs, there is a higher percentage of traditionally certified teachers in non-charter schools than in charter schools. There are more female teachers in both charter and non-charter schools and the percentage of female teachers from traditional certification programs is larger than the percentage from alternative certification. As such, male STEM teachers are more likely to earn alternative certifications than they are to earn standard certifications. With respect to ethnicity, most teachers in both charter and non-charter schools identify as White. In addition, White and Latinx teachers are more likely to attend standard teacher preparation programs, whereas Black teachers are more likely to attend alternative programs.

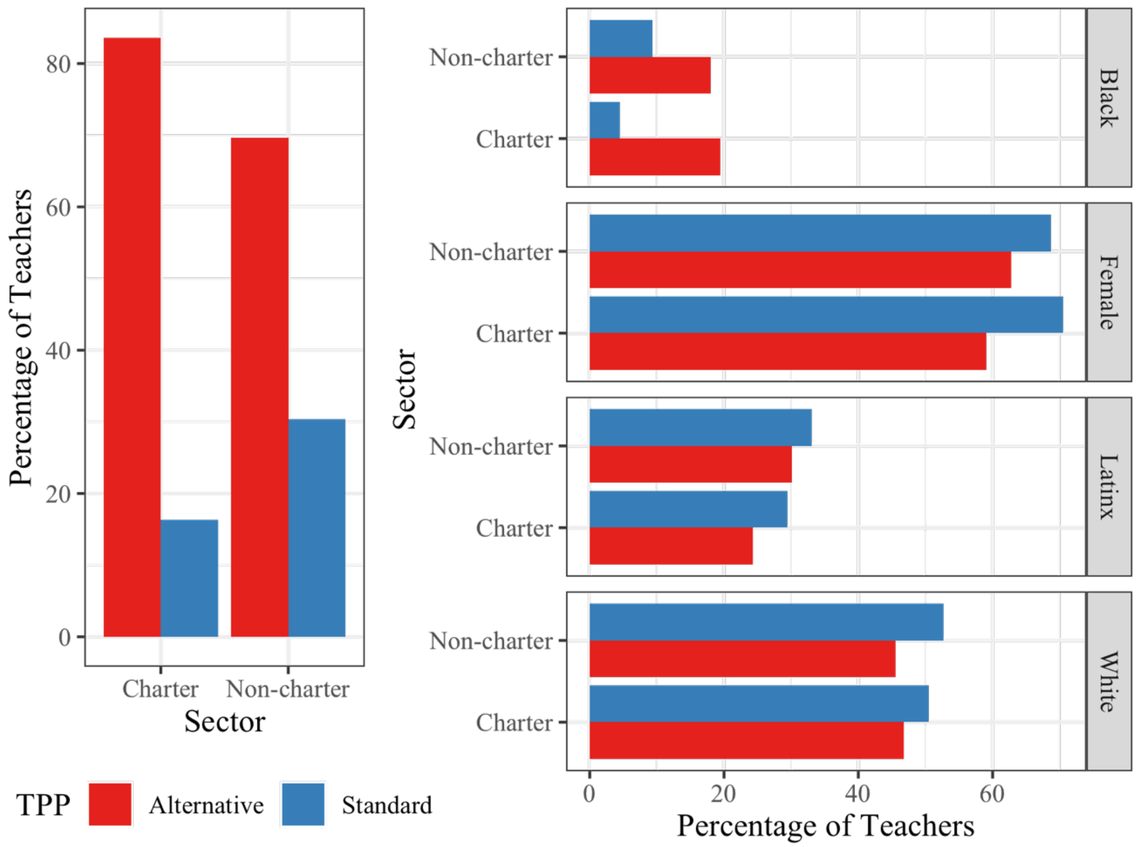

Figure 21. Demographic characteristics of teachers included in the study by preparation pathway and sector.

In addition to limiting the data analyzed to Texas counties in which both charter and non-charter schools operate, the student sample is limited to students with valid "standard" test scores in both 8th and 9th grade. During the time period over which data was analyzed for this study, several different versions of standardized exams in STEM subjects were available for students, including linguistically modified versions and versions with accommodations tailored specifically for students qualifying for special education services. Since modified tests are substantively different from standard exams, comparing student performance on the same version of the exam from one year to the next is important. As such, in limiting analysis to students with only valid "standard" scores, it is not possible to generalize the causal estimate of the joint effect of teacher preparation pathway and school sector to other sub-populations, such as students qualifying for special education services or students whose first language is not English.

In the ERC data set, teacher certification is represented in two ways: certification type (such as standard, alternative, one-year, or emergency certification) and certification program (such as standard, alternative, or post-baccalaureate). Moreover, THEBC data include the organization from which each teacher was certified. While there is tremendous heterogeneity in the types of teacher preparation programs, this work defines traditionally certified teachers as those who earned a standard certificate (meaning they completed pre-service teaching before entering the profession) and graduated from a standard, university-based preparation program. Alternative teachers are those who do meet the definition of traditional certification operationalized above (including teachers with a standard certificate from an alternative program or teachers with an alternative certificate from a standard program). In general, alternative teachers were issued probationary certificates (meaning their first year in the classroom is occurring concurrently with their participation in a teacher preparation program) from alternative, non-university based programs. Due to the fact that this study is interested in comparing traditionally and alternatively certified teachers, any teacher whose first certificate was neither standard nor alternative was dropped from the data set.

The crossover design in this study compares students either transitioning from charter schools or to charter schools between their 8th and 9th grade years. The average demographic characteristics of transitioning students included in the present study for both mathematics and science are provided in Table 12. This table gives results from matched-pair t-tests determining whether or not demographic differences between students transitioning from or to charter schools are statistically significant. As shown, there are statistically significant differences in the percentages of Asian, Black, economically disadvantaged, gifted, limited English proficient (LEP), Latinx, SPED, and white students in these two groups.

Table 12. Paired-sample t-tests comparing average demographics of students transitioning from and to charter schools in the present study.

	Mathematics				Science			
	From Charter	**To Charter**	**t-Score**	**Sig.**	**From Charter**	**To Charter**	**t-Score**	**Sig.**
% Asian	3.05	3.76	3.52	***	3.38	4.13	3.62	***
% Black	15.30	18.16	6.94	***	15.28	17.54	5.64	***
% Econ. Dis.	74.10	67.15	-13.86	***	73.53	65.81	-15.50	***
% Gifted	13.97	11.06	-8.20	***	14.72	12.70	-5.53	***
% LEP	18.49	15.63	-7.05	***	17.70	15.12	-6.56	***
% Latinx	69.75	63.51	-12.07	***	69.25	63.08	-12.07	***
% Multiracial	1.06	1.10	0.31		1.10	1.17	0.57	
% Native Amer.	0.29	0.30	0.08		0.33	0.26	-1.20	
% Pacific Islander	0.05	0.08	1.07		0.07	0.07	0.09	
% At Risk	45.87	45.64	-0.41		44.42	44.36	-0.11	
% SPED	5.93	7.31	5.00	***	5.22	6.90	6.42	***
Avg. Test Score	-18.15	-17.36	0.64		10.58	9.32	-1.07	
% White	10.48	13.09	7.30	***	10.60	13.75	8.82	***

* denotes $p < 0.05$; ** denotes $p <0.01$; *** denotes $p < 0.001$

Despite statistical significance, these differences are typically ~6% or smaller, with the notable exception that a smaller percentage of economically disadvantaged students transitions to charter schools than the percentage of economically disadvantaged students who transfer from charter schools. While demographic terms measuring the association of student demographic characteristics and test score are included in the model (Equation 12, discussed in the following section), that there are substantive differences between the characteristics of students transferring from and to charter schools necessitates that results from this model, especially causal inference, be interpreted with caution. Sector differences in the types of students who transition into or out of charter schools from 8th to 9th grade could result from recruiting and retention practices within charter schools (e.g., that charter schools have reportedly targeted "higher achieving" students through strategic location and marketing practices).

ANALYTIC METHODS

To estimate the joint causal effects of teacher preparation pathway and school sector upon student outcomes in STEM disciplines, I employ two casual methods. The first method is a hybrid crossover, nonrandomized block design, in which data available are subset to include students switching between sector. These students are then compared within blocks (schools and counties) to estimate the joint causal effect of teacher preparation pathway and school sector upon performance in STEM disciplines. For the second method, I create a DAG to articulate the underlying casual structure of the system and proceed to use this DAG to develop a statistical model that can be used to estimate the joint causal effect of teacher preparation pathway and school sector upon student outcomes in STEM. In the discussion section, I evaluate the merits of these two methods.

Hybrid Crossover and Nonrandomized Block Design

Although the data is not randomized, the crossover and nonrandomized block design seeks to estimate a causal effect by constructing a sample of comparable students who have enrolled in both charter and non-charter public schools. Simply comparing charter and non-charter students may produce biased estimates, as enrolling in a charter school requires both that a charter school be available to a student and that a student's family elects to apply to a charter school. As such, it is likely that charter and non-charter students are substantively different from one another. To control for these differences, this research design compares students who switched between school sector during the transition from 8th to 9th grade. Although this does not control for the possible reasons why a student may switch from a non-charter to a charter school (or vice versa) at this juncture, it does control for variables associated with enrolling in schools of choice—namely that students had to apply to a charter school at some point in their educational trajectory.

In addition to controlling for student differences, it is important to control for school level environmental and demographic differences that vary by county in Texas. To control for these differences, this method takes advantage of a nonrandomized block design by including a fixed effect that accounts for the counties in which charter and non-charter schools are situated in addition to fixed effects that control for students' schools. In doing so, charter and non-charter schools will be compared to other schools that are located in a similar geographical setting, and students will be compared within their schools. The counties highlighted in dark blue in the top left panel of Figure 18 are the blocks within which charter and non-charter schools are compared.

Regression Model

To ascertain the joint effects of teacher preparation pathway and school sector upon student outcomes in STEM disciplines using a crossover, nonrandomized block design, the multi-level regression model specified by Equation (12) is constructed:

$$Y_{i,g,y,s,c} = \alpha_i + \alpha_g + \alpha_y + \beta_P P_i + \beta_C C_i + \beta_{int} P_i C_i + \sum \beta_X X_i + \gamma_s + \gamma_c + \epsilon_{it} \qquad (12)$$

In Equation (12), $Y_{i,g,y,s,c}$ is the math or science test score (which has been standardized such that the mean score is 0 and the standard deviation is 1) for student i in grade g, year y, school s, and county c. Alpha terms (α_i, α_g, and α_y) are fixed effects coefficients for students, grades (8th and 9th), and years (2012 – 2019) included in this study. P_i is a binary variable indicating whether or not a student's teacher was certified through an alternative certification pathway, C_i is a binary variable indicating whether or not a student attended a charter school, and P_iC_i is the interaction between pathway and school sector. The beta coefficients for these terms (β_P, β_C, and β_{int}) give the causal estimates for the individual and joint effects of teacher preparation pathway and school sector upon student learning gains in math and science, as measured by increase or decrease in math and science exam scores. X_i are demographic characteristics for student i (including ethnicity, socioeconomic status, and designation as special education (SPED), limited English proficiency (LEP), and gifted), and the corresponding beta coefficients give the estimated change in test score associated with these demographic characteristics. The gamma terms in Equation (12) account for the nonrandomized block design of this experiment. Due to the fact that this work seeks, in part, to estimate the causal effect of charter schools, fixed effects coefficients for the schools included in this study would be collinear with the charter school indicator, C_i. Therefore, γ_s is a school-level random effects coefficient to control for school level characteristics. As schools are blocked within county, γ_c are fixed effects for county. Including these fixed and random effects coefficients ensures students are compared within schools and schools are compared within county.

While other studies examining the causal effect of charter schools upon student outcomes take advantage of the randomized lottery admissions process in oversubscribed charter schools, doing so is not possible in this work due to the fact that lottery results are unavailable in the Texas ERC. Nevertheless, by employing a crossover design to identify students to include in this study and accounting for the "blocks" by which teachers and campuses are grouped (e.g., county in which each school is located), this method attempts to ensure that adequate comparisons between students' teachers and schools are conducted in estimating a causal effect of teacher preparation pathway and school sector upon student outcomes in STEM.

Directed Acyclic Graphs

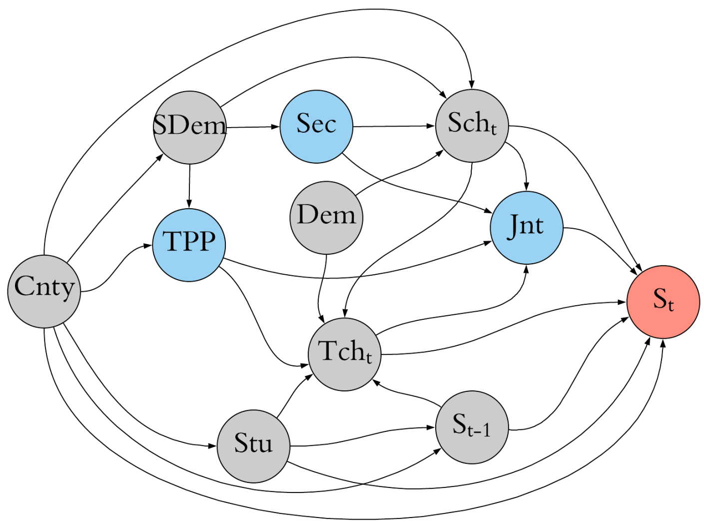

Figure 22. Directed acyclic graph illustrating the casual mechanism by which teacher preparation pathway (*TPP*) and school sector (*Sec*) are hypothesized to affect student test scores in STEM subjects (S_t). Red indicates the outcome variable of interest, blue represents the causal effects being estimated, and grey nodes represent other covariates.

In a directed acyclic graph, nodes represent variables and arrows between nodes are directed to indicate how the two variables are causally related. In Figure 22, a DAG is provided that shows how school sector and teacher preparation pathway (in addition to a number of other variables) are hypothesized to impact student performance on standardized exams in STEM. Arrows pointing from one variable to another, indicate that the first variable has a causal effect upon the second. For example, the DAG in Figure 22 indicates that six variables affect a students' test score in year *t* (S_t). These variables are that students' school in year *t* (Sch_t), teacher in year *t* (Tch_t), the joint effect of teacher preparation pathway and school sector (*Jnt*), student level characteristics (*Stu*) that will be assumed to be invariant across time, county level characteristics (*Cnty*), and the student's score on the standardized exam in the prior year (S_{t-1}).

The joint effect of teacher preparation pathway and school sector (*Jnt*) depends causally upon school sector (*Sec*) and teacher preparation pathway (*TPP*), but these effects are also mediated by individual schools and teachers. Given that teachers seek employment in schools with ideological match, it is presumable that the joint effect of teacher preparation pathway and school sector is manifests at the school and teacher level. Thus, the DAG shows that school sector affects individual schools, teacher preparation pathways affect teachers, and all four of these variables affect the joint effect of teacher preparation pathway and school sector upon student performance in STEM disciplines.

In addition, it is important to consider the broader system in which teacher preparation pathways and charter and non-charter schools operate. These educational reforms often target certain student populations. The DAG in Figure 22 accounts this by including a school demographics (*SDem*) variables, which affect teacher preparation pathway (*TPP*), sector (*Sec*), and individual schools (*Sch*). Teacher preparation pathways have mechanisms by which their graduates work in schools serving specific students from specific demographic backgrounds. Similarly, in the era of school choice, schools are often positioned such to work with students from specific demographic backgrounds. Individual student demographic variables (*Dem*) are also included in the DAG. Causal inference prohibits demographic variables from being causal variables (e.g., one's race does not cause one to have a higher or lower level intelligence) (Pearl, 2009b); however, I include demographic variables in the DAG to account for the socially constructed nature of both race and gender. Individual student demographics may causally influence how students are assigned to teachers within a school, and their demographics may also affect where they choose to go to school. Thus, student race and gender are not causal variables in and of themselves, but this DAG indicates that these identities have causal relationships due to the social structure of the educational system. Finally, geographic variables (captured here as county, *Cnty*) affect teachers, schools, students, and student test scores. School systems are parts of a broader community, and the county level variable is meant to account for the community-level attributes that influence various factors of the school system, including schools, teachers, students, and even student performance on standardized assessments. Individual students (Stu) are also included in the DAG, as unobserved student level characteristics affect their test performance (in both the current and prior year) in addition to how they interact with a given teacher.

Statistical Models

Of main interest are the effects of preparation pathway, sector, and their interaction (*TPP*, *Sec*, and *Jnt*) upon student test score (S_t). In order to obtain an unbiased estimate, it is important to consider confounding variables—those that affect both treatment and outcome in the experimental design and to block "back door" paths that cause spurious correlations between the treatment and the outcome. Statistically, it is possible to condition on confounding variables and other variables that block back door paths by including these variables in a regression model. Provided the DAG accurately captures the underlying causal mechanisms of the system, conditioning on these variables by including them in regression models serves to reduce bias in the casual estimate of the effect of treatment on the outcome. Adding additional covariates serves to make this estimate more precise.

Using the R package "ggdag," the DAG provided in Figure 22 is adjusted to show the minimally adjusted sets of variables on which it is necessary to condition (adjust) in order to estimate the joint causal effect of teacher preparation pathway and school sector upon student test scores in math and science. As can be seen, there are four distinct sets of variables on which it is possible to condition in order to estimate the causal effect of interest. Each of the decomposed DAGs are provided in Figure 23.

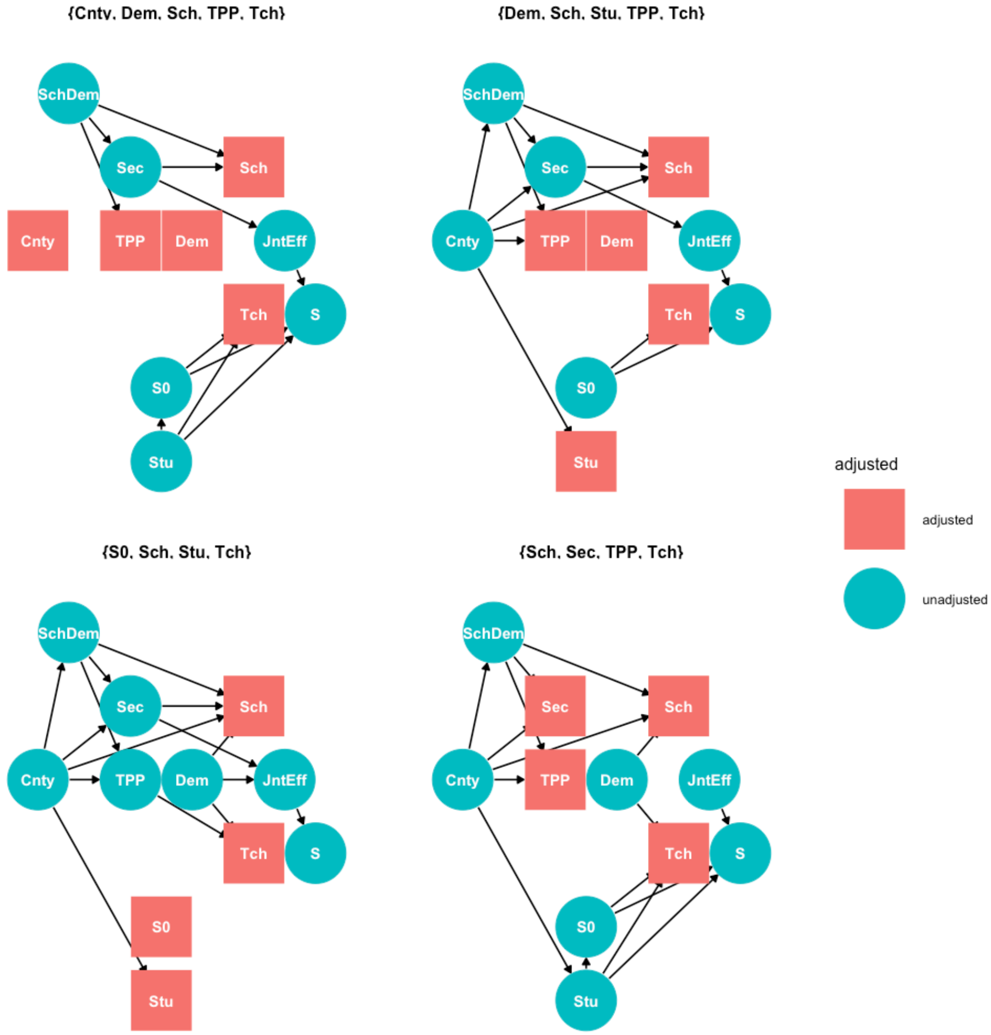

Figure 23. Minimally adjusted sets of the DAG provided in Figure 22.

By adjusting the DAG in Figure 22, giving those shown in Figure 23, it is possible to develop a model that can be used to estimate the joint effect of teacher preparation pathway and school sector upon student performance on standardized exam performance, as in Equation (13):

$$S_{iy} = \sum_{j=1}^{3} \beta_{sj} S_{i,y-1}^{j} + \beta_{Jnt} P_i C_i + \beta_P P_i + \beta_C C_i + \sum \beta_X X_i + \sum \beta_Y Y_j + \sum \gamma_k + \epsilon_i \qquad (13)$$

In this model, students' scores in mathematics and science in year *y* are regressed on their prior year scores (*y* – 1) to third order, individual and school-wide demographic characteristics, and flags to indicate whether or not that student was enrolled in a charter school and to indicate whether or not that student was taught by a teacher from an alternative certification program. The interaction between teacher preparation pathway and school sector is the main variable of interest. In addition to these covariates, gamma terms (indexed by *k*) represent fixed effects for years *y* included in the study and random effects for teacher *t* school *s* and county *c*, so that students are compared within teachers, teachers are compared within schools, and schools are compared within counties.

Using a DAG to develop the model specified by Equation (13) makes it possible to evaluate the joint causal effect of teacher preparation pathway and school sector with greater generalizability. Rather than restricting this model to students switching between sectors from their 8th to 9th grade years, all 9th grade students enrolled in a school that is located in a county included are analyzed. Therefore, the causal estimate provided by this model will have greater external validity than the estimate provided by the model specified by Equation (12).

RESULTS

Results from both causal methodologies are presented in the following subsections. First, estimates from the regression model for the hybrid crossover nonrandomized block design are presented. In the next subsection, results from regression models specified to condition on the variables indicated in the adjusted directed acyclic graphs from Figure 23 are presented.

Crossover Nonrandomized Block Results

Estimates from the multilevel regression model specified by Equation (12) are provided in Table 13. The beta coefficients for teacher preparation pathway, charter school, and their interaction together provide a causal estimate of joint effect teacher preparation pathway and school sector upon student outcomes in math and science.

Table 13. Coefficients from regression model specified for the hybrid crossover, nonrandomized block research design in mathematics and science.

Crossover, Nonrandomized Block Design						
	Mathematics			**Science**		
Coefficients	**Est**	**S.E.**	**Sig.**	**Est.**	**S.E.**	**Sig.**
Intercept	-0.42	0.46		-3.04	0.59	***
Chart	-0.15	0.03	***	-0.04	0.03	
Alt. Cert.	-0.03	0.01	***	0.00	0.01	
Chart, Alt. Cert.	0.02	0.01		0.01	0.01	
Male	0.11	0.06	*	0.47	0.06	***
Black	0.13	0.06	*	0.12	0.05	*
Latinx	-0.12	0.05	*	-0.01	0.05	
Multiracial	0.06	0.06		0.06	0.05	
Nat. Am.	-0.10	0.07		0.08	0.06	
Pac. Isl.	-0.40	0.13	**	0.27	0.09	**
White	-0.11	0.05	*	0.03	0.05	
9th Grade	-0.16	0.04	***	-0.38	0.09	***
Econ. Dis.	0.02	0.01	**	0.02	0.01	***
Gifted	0.02	0.01	.	-0.03	0.01	*
LEP	0.01	0.01		-0.01	0.01	
SPED	0.01	0.02		-0.07	0.02	***
*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, . $p < 0.10$						

The coefficient for charter schools suggests that students with traditionally certified teachers in charter schools experience a 0.15 standard deviation decrease on mathematics exams and a 0.04 standard deviation decrease on science exams as compared to students taught by traditionally certified teachers in non-charter schools. The coefficient for teacher preparation indicates that alternatively certified teachers cause students' test scores to decrease by 0.03 standard deviations in mathematics relative to traditionally certified teachers in non-charter schools, but there is no effect of alternative certification detected in science. The effect of alternative certification upon student test scores is not independent of employment in charter schools, as indicated by the interaction term. The interaction term suggests that students taught by alternatively certified teachers in charter schools experience a 0.16 and 0.03 standard deviation decrease on math and science tests, respectively (these numbers are determined by summing the teacher preparation pathway, charter school, and interaction term coefficients). The positive interaction term for both mathematics and science suggests that alternatively certified teachers are more effective in charter schools than they are in non-charter public schools.

The only statistically significant results detected are for the independent effects of charter schools and alternative certification upon students' math scores. The effects of these reforms are not statistically significant in the model examining students' performance on standardized exams in science, and the interaction is not statistically significant in either model. That the independent causal effects of charter schools and alternative certification programs are negative in mathematics but undetected in science is consistent with other causal studies investigating student performance in STEM disciplines in Texas (Marder et al., 2020). The reason for this difference is unclear but warrants additional investigation. While positive interaction between charter schools and alternative certification indicates that alternatively certified teachers are more effective in charter schools than they are in non-charter public schools, lack of statistical significance brings into question the robustness and practical significance of this effect. While ideological similarity may attract certain kinds of teachers to charter schools, it is not clear that this ideological match has any positive effect upon student performance. At best, this effect may slightly mitigate the independent negative effects of charter schools and alternative certification upon student performance in STEM.

Regression and DAG Results

Table 14. Regression coefficients for the model specified from the directed acyclic graph adjustments given in Figure 23.

DAG, Campus Averages						
	Mathematics			**Science**		
Coefficients	**Est.**	**S.E.**	**Sig.**	**Est.**	**S.E.**	**Sig.**
Intercept	-0.8	0.08	***	-0.31	0.07	***
Chart	0.03	0.03		0.07	0.02	**
Alt. Cert.	-0.02	0.01	***	0.00	<0.01	
Chart, Alt. Cert.	-0.02	0.03		-0.02	0.02	
Pre-Score 1	0.76	<0.01	***	0.60	<0.01	***
Pre-Score 2	0.13	<0.01	***	0.05	<0.01	***
Pre-Score 3	-0.07	<0.01	***	-0.02	<0.01	***
Male	-0.04	<0.01	***	-0.04	<0.01	***
Black	-0.16	<0.01	***	-0.12	<0.01	***
Latinx	-0.15	<0.01	***	-0.12	<0.01	***
Multiracial	-0.15	0.01	***	-0.09	0.01	***
Nat. Am.	-0.13	0.01	***	-0.09	0.01	***
Pac. Isl.	-0.12	0.01	***	-0.13	0.01	***
White	-0.15	<0.01	***	-0.09	<0.01	***
Econ. Dis.	-0.04	<0.01	***	-0.05	<0.01	***
Gifted	0.15	<0.01	***	0.16	<0.01	***
LEP	-0.03	<0.01	***	-0.08	<0.01	***
SPED	-0.14	<0.01	***	-0.17	<0.01	***
*** p < 0.001, ** p < 0.01, * p < 0.05, . p < 0.10						

Results from the regression model specified to condition on the minimally adjusted sets of variables diagramed in Figure 23 are provided in Table 14 for both mathematics and science. Estimates from these models paint a different picture than the estimates from the model constructed for the crossover, nonrandomized block design. As opposed to consistent negative effects of charter school attendance upon student performance on student tests in math and science, this model suggests that charter schools are responsible for increasing students' scores by 0.03 standard deviations in mathematics and by 0.07 standard deviations in science, an effect that is statistically significant.

In mathematics, alternatively certified teachers are estimated to cause a 0.02 standard deviation decrease in students' math scores in mathematics but have no effect upon student test scores in science. In contrast to the models specified for the crossover, nonrandomized design, the interaction between charter schools and alternatively certified teachers is associated with decreases in students' test scores in both mathematics and science, suggesting that alternatively certified teachers in charter schools are less effective than alternatively certified teachers in non-charter schools; however, these interaction terms are not statistically significant.

Coefficients indicate that mathematics and science outcomes vary by student demographic groups. Relative to Asian students, Black, Latinx, multi-racial, Native American, and Pacific Islander students have lower scores. Students identified as SPED, LEP, and economically disadvantage also have statistically significant decreases in test scores for both mathematics and science, while students identified as gifted tend to have statistically significant increased exam performance.

DISCUSSION

Results from the crossover, nonrandomized block design suggest that although charter schools and alternatively certified teachers decrease students' standardized exam scores in mathematics and science, a positive interaction term between certification pathway and school sector mitigates the negative effects of these two reforms. This gives some credibility to the notion that ideological match between a teacher and school may have a positive effect upon student performance; however, the importance of this effect is minimal at best, considering that the interaction between school sector and certification was not statistically significant. Thus, results from this model suggest that the notion of ideological match between teacher and context does not manifest in any appreciable change in student performance on standardized exams. Of greater concern, particularly in mathematics, are the negative independent effects of charter schools and alternative certification programs upon student achievement. This finding should give policy makers pause when advocating for the continued expansion of charter schools, alternative certification, and other market-based reforms. The lack of any statistically significant effect of school sector or teacher preparation pathway in science, particularly in light of mathematics results, using this research design is puzzling, but consistent with results reported elsewhere (Marder et al., 2020). This is likely an artifact of how the models were constructed, namely that the individual campus effects account for greater variation in test performance.

Results from the regression model designed to condition on variables such to block “back-door-paths” between the treatment (joint effect of charter school and alternative certification) and the outcome of interest (student performance on science and mathematics standardized exams) tell a much different story. Although the negative effect of alternative certification is robust to both research designs, the effect of charter schools upon student exam scores is positive in the DAG design, a finding which is statistically significant in science.

Such discrepant findings necessitate consideration of which estimate should be trusted. To do so, it is important to discuss the relative merits and drawbacks of each design. In the crossover design, controlling for student-level factors that may confound the treatment and the outcome is achieved by limiting analysis to students who switch between sectors. This assumption may not be valid, as it is possible that students leaving charter schools after 8^{th} grade have different motivations for switching sector than students choosing to enroll in charter schools after their 8^{th} grade. Thus, there may be other unobserved factors that serve to confound the treatment and outcome that were assumed to have been removed when analyzing students who switch sector. Moreover, by inspecting paired-sample t-tests in Table 12, it is evident there are substantive differences between the sets of students switching sectors (either to or from charter schools) in their transition from 8^{th} to 9^{th} grade. That differences in the characteristics of students switching from and to charter schools in the transition from 8^{th} to 9^{th} grade suggests that the causal inferences from the results reported herein be interpreted with caution. There may be unobserved confounding variables affecting the estimates obtained from the model specified by Equation 12.

The results from the regression model specified to match the DAG provided in Figure 22 are to be trusted if the DAG truly represents the causal mechanisms between the variables included in the study. If the DAG does not accurately capture the true causal underpinnings of the educational system analyzed, then the causal estimates are not reliable. Although this DAG represents one theory about how variables are causally related to one another, there is fairly little consensus as to the causal structure of social systems in extant literature. Moreover, the assumptions about what demographic variables mean substantively (e.g., that these variables capture the causal effects attributed to students' demographic characteristics through the socially constructed nature of these demographics and their interaction with a social system) could lead to bias in the statistical model constructed. Should demographic variables substantively represent something else about a student's interaction with the school system, the DAG may have to be modified accordingly.

The strength of using DAGs to articulate the underlying structure is that they do not make any assumptions about the functional relationships between variables and that they force researchers to articulate a causal theory about the system under investigation. However, doing so is a tremendous challenge, as consensus about causal mechanisms in a social system is not often achieved. Yet, if given a correct causal DAG, results from the corresponding model can be more readily generalizable. At best, the crossover design can be generalized to other students who switch sector from one year to the next, a far smaller set. Moreover, caution is still warranted, as this design does not necessarily require the articulation of a causal structure and may therefore not account for confounding variables that serve to bias between the treatment and outcome.

It is worthwhile to note that this study, as are others, is limited in using test scores to ascertain the differences between "traditional" elements of the public education and those that have burgeoned in an era of market-based reforms. As Berends and Donaldson (2016) argue, it is important for research on market-based reforms in education to investigate the programmatic differences that impact student achievement differences by sector. Rather than using only test scores as outcomes, research into student course-taking patterns, college success, and other metrics can elucidate the effects of market-based reforms in more substantive ways. While test score data is instructive in illustrating the efficacy of different educational reform efforts, in this case charter schools and alternative teacher certification pathways, research moving forward should investigate the ways in which these reforms have affected student engagement in and access to STEM more broadly.

Chapter 5: Conclusion

The broad goal of this dissertation project was to evaluate how the growth of market-based reforms in within public education—specifically charter schools and alternative teacher certification pathways—have impacted participation and engagement in STEM, particularly among ethnic minority student populations that have been historically underrepresented in STEM disciplines. Poor performance in STEM disciplines and inequitable educational attainment are two often cited shortcomings critics attribute the "traditional" public education system. Although charter schools and alternative certification pathways were not created specifically to address these shortcomings, policy documents and advocates of market-based education have offered these specific reforms as means by which to achieve improved educational outcomes. Therefore, if improving performance in the STEM disciplines and reforming the education system to lead to more equitable educational outcomes among a socioeconomically diverse student populations are priorities leading to calls for education reform, then it is pertinent to investigate the role of market-based reforms in achieving these metrics.

In addition to evaluating market-based education reforms using metrics that have been cited to garner national support for the expansion of these reforms, it is also important for research to attend to the mechanisms that explain differential student outcomes by teacher preparation pathway and school sector and to analyze STEM outcomes more generally, looking beyond performance on standardized exams. Research that compares student outcomes by sector and preparation pathway is of limited utility, as these results cannot be used to inform policy makers of the best practices that are most likely to yield to positive student outcomes. Similarly, research that uses only performance on standardized exams to evaluate the efficacy of education reform fails to account for a breadth of outcomes that are arguably more meaningful for students. Calls to attend to the mechanism responsible for the effects of educational reforms and to a broader definition of "outcomes" acknowledge the complexity and nuance of the public education system, whereas the capacity of other studies to do so is limited.

If the success of education reforms is measured by their abilities to improve student outcomes in STEM disciplines and to lead to equitable educational outcomes by across diverse socioeconomic demographics, then charter schools and alternative teacher certification programs leave much to be desired. While some prior evidence has shown that, in certain contexts, charter schools improve student performance on standardized exams and increase college enrollment (Davis & Heller, 2017; Dobbie & Fryer, 2015, 2016), results from the first study indicate that the breadth of these successes is fairly minimal. While charter schools do increase student enrollment in post-secondary institutions, charter schools do not appear to equip students with the tools they need to succeed at post-secondary institutions nor do they increase the likelihood that students pursue STEM disciplines. That charter schools, which tend to serve socioeconomically disadvantaged student populations, increase college enrollment, but do not appreciably increase post-secondary attainment is of concern, considering the high price tag of post-secondary education. If students are in positions to acquire debt without realizing the benefits of post-secondary education (namely a degree), this may serve exacerbate economic disparities in the long term.

Often, charter schools aggressively target standardized exams and post-secondary enrollment and cite success with these two metrics as evidence of their success in a more general sense. Given the political and public scrutiny facing the public education system writ large, all schools are incentivized to improve standardized test scores and college enrollment rates (which are often reported publicly). With greater autonomy than district schools, one plausible explanation that some charter schools are more effective at improving test performance and college enrollment is that they have greater latitude with which to target these outcomes specifically (e.g., such as additional instructional time that can be used to give students more practice on standardized exams). That charter schools do not affect more important outcomes (degree attainment or STEM degree) suggests that their benefit is temporally limited. Moreover, results from earlier work exploring STEM course taking patterns in charter and non-charter schools (David et al., 2020) suggest charter schools have more limited course options. It is plausible that these educational limitations may allow charter schools to be more effective at achieving immediate outcomes (test score improvements and college enrollment) without appreciably improving long-term student outcomes, which are arguably more important.

While charter schools and alternative teacher certification programs are distinct education reforms with unique histories, I argue their concurrent expansion motivated over similar concerns about the public education system render these reforms interdependent. As descriptive results from Texas shows, alternatively certified teachers are overrepresented in charter schools. Thus, it is important for education policy researchers to jointly consider charter schools and alternative certification pathways. Extant literature that has largely explored these reforms independently does not account for the ways in which these reforms are ideologically and practically aligned.

The effects of alternative teacher certification programs in two of the three studies—investigating course assignment and identifying a joint causal effect of charter schools and alternative certification—suggest that alternatively certified teachers are less effective than traditionally certified teachers in STEM. The negative effects of alternative certification were robust to both causal models constructed in Chapter 4, and alternative certification is associated with increased turnover and a higher likelihood of being assigned to elective STEM courses, rather than to advanced or tested STEM courses. These trends are concerning, particularly considering that elective STEM courses escape the scrutiny of high-stakes accountability. While I do not argue that high-stakes accountability is a positive aspect of the current public education system, that alternatively certified teachers are shown to decrease student outcomes on standardized exams and also systematically transferred to courses where these negative impacts cannot be detected may mask the true breadth of how alternative certification impacts student performance.

Another finding that warrants concern is that both charter schools and alternative certification are associated with higher mobility. Alternatively certified teachers and teachers in charter schools are more likely to leave the profession or to transfer to new courses and/or new schools. Teachers with more experience are often more effective, so it is troubling that charter schools and alternative certification lead to higher turnover, particularly when considering that alternative teachers are more likely to work in charter schools. Rather than providing students with a better education, the joint impact of turnover that alternative certification and charter school employment has upon students in the "parallel" education system could serve to exacerbate already troubling achievement gaps along socioeconomic lines.

While much of the existing research on charter schools and alternative certification programs has pit these two reforms against their corresponding elements in the traditional public education structure, I argue it is important to continue for researchers to attend to the mechanisms by which differential outcomes between market-based institutions and traditional institutions are achieved. By doing so, it may be possible to unearth structures that may have greater influence upon student achievement than sector and certification differences. For example, the effects of secondary STEM course-taking upon students' post-secondary attainment is more robust than the effects of sector. Although there are some significant interactions between these two variables, the effects of course-taking were more robust to the models included in the first study. As such, differences between sector may not be as important as different school practices. Moreover, in attending to mechanisms within schools that may be related to differential student outcomes, other insights become evident and may warrant policy attention, such as the increased mobility in charter schools that is further exacerbated by high mobility among alternatively certified teachers.

I do not think the results from the studies included in this dissertation point conclusively to whether or not market-based reforms are better than the traditional structure. However, it is clear that they have not been successful at improving educational outcomes in areas that have been identified as priorities. Nevertheless, focusing only upon sector differences often neglects consideration other systematic elements of the education system that may more pervasively serve to uphold structures leading to equity. In the debate over market-based reforms, it is particularly important to consider these elements in order to achieve the goals for equity, STEM education, and equity within STEM education.

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